Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

Mineral Sciences Laboratories

Laboratoires des sciences minérales

Canada

NABST
COMMITTEE ON FEDERAL EXPENDITURES IN SCIENCE AND TECHNOLOGY
(THE LORTIE COMMITTEE)

BOOK II

WORK AREA DESCRIPTION

October 1989

This document is an unedited interim report prepared primarily for discussion and internal reporting purposes. It does not represent a final expression of the opinion of the Canmet Centre for Mineral and Energy Technology (CANMET)

Ce document est un rapport provisoire non corrigé préparé principalement pour fin de discussion et de documentation interne. Il ne représente nullement l'expression définitive de l'opinion du Centre canadien de la technologie des minéraux et de l'énergie (CANMET)

119 pp

MINERAL SCIENCES LABORATORIES
DIVISION REPORT MSL 89-117 (IR)

MICROMEDIA

CONTENTS

MINERAL SCIENCES LABORATORIES

WORK AREAS

	Page
Process Mineralogy	II-1
Mineral Processing	II-11
Computer-Aided Mineral Processing	II-22
Pyrometallurgy	II-27
Hydrometallurgy	II-38
Biotechnology	II-60
Environment	II-68
Concrete Technology	II-78
Ceramics	II-90
Analytical Standards and Methods	II-101

PROCESS MINERALOGY

GOAL AND SCOPE:

To develop, apply and transfer improved mineralogical techniques in order to identify, evaluate and optimize processing routes.

Activity is focussed in the following Major Project areas:

1. Mineralogical Evaluation of Process Products
2. Precious Metals
3. Zinc Processing
4. Rare-earths Mineralogy.
5. Tailings characterization.

PERSONNEL:

Four Ph.D. Process Mineralogists
One Ph.D. X-Ray Diffraction Specialist
One M.Sc. Process Mineralogist
One B.Sc. X-ray Diffraction Specialist
Six Technicians

Below are listed the names, qualifications and expertise of all technical and scientific personnel working in this area. An asterisk before the name indicates that a detailed Curriculum Vitae is included in Book Three.

J.M. Beaulne — Research Technician
14 years at CANMET.

Expertise in preparing polished-thin sections and polished sections and in scanning electron-microscopy for studying ores.

K.M. Besso — B.Sc. (Honours) Geology, Concordia University, 1977.
3 years at CANMET.

Expertise is X-ray diffractometry, including X-ray micro-analysis and quantitative X-ray analysis, with particular emphasis on ceramic products and clay minerals.

***L.J. Cabri**

B.Sc. Geology, University of Witwatersrand, 1954.
B.Sc. (Honours) Geology, University of Witwatersrand, 1955.
M.Sc. Applied Geology, McGill University, 1961.
Ph.D. Geology, McGill University, 1965.
25 years at CANMET.

Expertise in mineralogy of precious metals (Au, Ag, platinum group elements) and in development and application of in-situ trace element analysis. Has wide international recognition.

P. Carrière

Research Technician
23 years at CANMET.

Expertise in X-ray diffractometer operation.

J.M. Greer

Technician
2 years at CANMET.

Expertise in preparing polished sections.

***J.L. Jambor**

B.A. (Honours) Geology, University of British Columbia, 1957.
M.Sc. Geology, University of British Columbia, 1960.
Ph.D. Mineralogy and Crystallography, Carleton University, 1966.
14 years at CANMET.

Expertise in mineralogy, particularly in characterizing ore deposits and in recognizing mineral properties that have a bearing on processing and on the environment. Internationally recognized authority on determinative mineralogy.

J.H.G. Laflamme

Research Technician
20 years at CANMET.

Expertise in microbeam analysis and in studying ore samples.

R. Lastra

B.Sc. Metallurgy, National Polytechnique Institute (Mexico), 1974.
M.Eng. Metallurgy, McGill University, 1981.
Ph.D. Metallurgical Engineering, McGill University, 1988.
6 months at CANMET.

Expertise in evaluating ores during processing and in image analysis of ores and mill products.

D.R. Owens

Chief Research Technician.
35 years at CANMET.

Expertise in microbeam analysis and in studying ore samples.

***W. Petruk**

B.Eng., Geology, University of Saskatchewan, 1954.
M.Sc. Geology, University of Saskatchewan, 1955.
Ph.D. Geology, McGill University, 1959.
29 years at CANMET.

Expertise in characterizing ores during mineral processing and in developing and performing image analysis of ores and mill products. Has wide international recognition.

R.G. Pinard

Research Technician
32 years at CANMET.

Expertise in image analysis.

J.T. Szymanski

B.Sc. (Honours) Chemistry, Kings College, University of London, 1959.
Ph.D. Inorganic chemistry, University of London, 1963.
18 years at CANMET.

Expertise in X-ray diffractometry and in crystal structure analysis.

J.M.D. Wilson

B.Sc.
M.A.Sc., Queens University
11 years at CANMET.

Expertise in characterizing ores during mineral processing, in materials balancing, and in image analysis.

FACILITIES:

Sample preparation facilities: cut-off saws, polishing and thin sectioning equipment, heavy liquid separation, magnetic separator.

High temperature laboratory: used for preparing microprobe standards:

Equipment: 2 microprobes, 2 scanning electron microscopes, 2 image analyzers, 5 optical microscopes, 1 Rigaku X-ray diffraction unit, 1 Guiner X-ray diffraction unit, 4 powder X-ray diffraction units.

CAPABILITIES:

- Identify minerals
- Characterize minerals and phases in ores and process products
- Find reasons for behaviour of minerals and phases during processing
- Indicate methods of improving recoveries of metal values, industrial minerals and energy minerals and materials.
- Identify reactions in products including concrete, mineral processing tailings, smelter and refinery products, etc.
- Identify phases in ceramics
- Characterize porosity in oil reservoirs.

MAJOR PROJECTS:

1. MINERALOGICAL EVALUATION OF PROCESS PRODUCTS:

OBJECTIVE:

To determine mineral behaviour during processing in order to help define the conditions that grinding circuits, concentrators, hydrometallurgical and pyrometallurgical processes must achieve to obtain optimum mineral and metal recoveries, and where warranted, to recommend improvements to design and/or operation procedures of mills and processing plants.

DESCRIPTION:

The projects included in this program are (1) determining characteristics that affect recoveries of Zn, Pb, Cu, Ag, and Au from base metal ores at Faro, Yukon; Hudson Bay Mining and Smelting, Flin Flon, Manitoba; and Brunswick Mining and Smelting, Bathurst, N.B.; (2) determining characteristics that affect recoveries of Fe from the iron ores in the Labrador trough; (3) incorporating mineralogical liberation data into a computer assisted mineral processing (CAMP) Program; (4) developing liberation models for incorporation into plant simulation designs; (5) characterizing the behaviour of minerals in conventional and column flotation cells; and (6) commissioning an update of an image analyzer.

INTERACTION:

Base Metal Ores:

CANMET personnel interact with mineral processing engineers of Curragh Resources in the Yukon, Hudson Bay Mining and Smelting in Manitoba, and Brunswick Mining and Smelting in New Brunswick.

Iron Ores:

CANMET personnel interact with management and mineral processing engineers of the Iron Ore Company of Canada, Quebec Cartier Mines Limited, and Wabush Mines Limited.

Image Analysis:

CANMET personnel interact with personnel from New Brunswick Research and Productivity Council, Fredericton, N.B., and the University of Manitoba, Winnipeg, Manitoba.

IMPACT:

The concentrator evaluation of Brunswick Mining and Smelting indicated a finer grind which was confirmed by metallurgical testing. A regrind circuit was installed, and zinc recoveries increased about 5%; value $5,000,000 to $10,000,000 per year. Subsequent tests indicated slime losses, and research is being conducted to solve the slime problem.

The concentrator of Hudson Bay Mining and Smelting was found to direct liberated sphalerite grains to the copper concentrate. Research on reagents is being conducted to solve the zinc loss problem.

The engineers of Hudson Bay Mining and Smelting were concerned with the gold losses to tailings, it was found that the nature of the gold is such that more gold cannot be recovered.

The concentrator of the Iron Ore Company of Canada was found to lose about 20% of the iron in the ore as small liberated grains. A new processing unit needs to be installed to recover the fine grained liberated iron. The value of the iron lost to tailings is about $100,000,000 per year. It is expected that the payback period for the unit would be about 6 months.

The technology of the image analysis system developed at CANMET has been transferred to New Brunswick Research and Productivity Council and to the University of Manitoba.

2. PRECIOUS METALS:

OBJECTIVE:

To provide an improved understanding on the amount and nature of submicroscopic gold, especially in refractory gold ores, and to provide an assessment of the distribution of platinum group elements in their ores.

DESCRIPTION:

Mineralogical/analytical studies that can assess quantitatively the mineralogical distributions of precious metals are carried out. The studies include development and applications of a sensitive trace element analytical technique for in-situ analysis of individual mineral grains.

INTERACTION:

These studies have involved a wide spectrum of collaboration ranging from Canadian mining companies (e.g., Noranda, Galactic Resources, Inco) to universities (e.g., University of Western Ontario, University of Guelph, University of Arizona) to other government departments and crown corporations (Geological Survey of Canada, B.C. Geological Survey, AECL), and to foreign government organizations (Max Planck Institut für Kernphysik, W. Germany, BRGM, France and IGEM, USSR).

IMPACT:

The impact from the studies of refractory gold ores is most significant as reflected by requests for information and for test work coming from Canada, USA and several other countries. The bulk of the test work is directed to Surface Science Western, London, Ontario and is considered a successful result of technology transfer. The results on the platinum-group elements continue to attract world-wide attention, and the new results from a joint contract with the B.C. Geological Survey are considered to be of great interest to exploration companies.

3. ZINC PROCESSING:

OBJECTIVE:

To determine whether there is a relationship between the trace-element content of sphalerite and its floatability.

DESCRIPTION:

Zinc concentrates differ widely in their impurity contents and trace element values, and the flotation response to sphalerite, the principal zinc mineral, is not fully understood. The research is directed at understanding the relationship between flotation response and the composition of the surface of sphalerite grains.

INTERACTION:

The project is partly funded by Noranda as a joint CANMET/Noranda project.

Close interaction with Noranda and Surface Science Western, London, Ontario has been developed. In addition, laser microprobe facilities outside Canada have been investigated because no suitable Canadian facility exists. The investigation has involved interaction with companies and universities in the USA, UK, and France.

IMPACT:

Success in the project could have a significant impact on the Canadian zinc industry including improved zinc and by-product recoveries as well as improved energy efficiencies.

4. RARE-EARTHS MINERALOGY:

OBJECTIVE:

To determine the mineralogy and the distribution of minerals in rare-earth deposits as a contribution to knowledge of the economic factors that effect deposit exploitation, and to provide mineralogical data that bear on processing options.

DESCRIPTION:

The principal deposits involved in the program are the Strange Lake Zr-Y-Be deposit in northern Quebec (on the Quebec Labrador boundary) and the Thor Lake Be deposit in the Northwest Territories. Studies of Thor Lake were undertaken initially on behalf of Highwood Resources Ltd. and Strathcona Minerals to determine the mineral distributions of Be and Y, and potential recoveries. Studies of Strange Lake material were initially on an ad hoc basis to assist Iron Ore Company of Canada because mineralogical knowledge of the deposit was at a primitive stage.

INTERACTION:

Thor Lake:

Visits were made to CANMET by personnel from the geology department of Highwood Resources, by the processing engineer from Strathcona Minerals, and by a professor and a M.Sc. student from the Geology Department of the University of Alberta, Edmonton. There also was interaction with members of the Mineral Deposits Subdivision of the Geological Survey of Canada. Liaison with all parties was maintained until Hecla Mining Co. took a controlling interest, whereupon continuous interaction was renewed.

Strange Lake:

Interaction mainly with the geology department of Iron Ore Company of Canada, who financially contributed to field sampling by CANMET.

IMPACT:

The mineralogical studies of the Thor Lake Be-rich zone had indicated that good recoveries of Be should be obtainable, and these are being achieved at mine production levels. Mineralogical predictions of poor recovery from the Y-rich zone has been confirmed.

Cost-recovery work undertaken for Hecla Mining Co. for another deposit in the Thor Lake area indicated that a substantial proportion of the particular element of interest would not be recoverable. The company has modified its work accordingly.

Results of cost-recovery work undertaken for a client to determine the sources of RE minerals at an exploration site in B.C. was an instrumental factor in the company's decision concerning an option for the property.

Results of the Thor Lake study were provided to Highwood Resources and Strathcona Minerals as a confidential report. The results were incorporated in papers published by company personnel and their associates, in scientific journals.

CANMET's expertise in rare-earth mineralogy has been recognized by industry. Hecla Mining Company has entered into a 3-year cost-shared agreement (total $654 K)d to support CANMET's studies in this field. Results will be transferred to Hecla as reports; as well, some dissemination of information to scientific and technical journals will occur.

A major mining company has initiated a significant cost-recovery project for mineralogical studies of a Canadian rare-earth deposit.

5. **TAILINGS CHARACTERIZATION:**

OBJECTIVE:

To provide mineralogical data for the characterization of the Waite Amulet sulphide-rich tailings and the arsenic-rich uranium tailings.

DESCRIPTION:

A comprehensive study of the Waite Amulet tailings (Noranda area, Quebec) was undertaken by Noranda Research Centre, Pointe Claire, Quebec, as a contract under the CANMET-supported "Reactive Acid Tailings" program. Under the terms of the contract, CANMET was obligated to provide mineralogical data. In another study mineralogical data were obtained for arsenic-rich uranium tailings that had been subjected to simulated weathering for the equivalent of ten years.

IMPACT:

CANMET's contractual obligations were fulfilled on schedule, and results were transferred to Noranda, to the Water Research Centre, University of Waterloo, to the Manitoba Mines Branch, and to mineralogists at the University of Manitoba.

Mineralogical studies of the Waite Amulet tailings were expanded beyond contractual obligations as it became evident that the CANMET-Waterloo collaboration was producing results in the forefront of scientific studies in this field.

CANMET-Waterloo collaboration has been extended to study primitive hardpans developed at Heath Steele, New Brunswick, and Waite Amulet.

A model for decreasing the acid draining from sulphide-rich tailings has been developed. Although the model must be tested, the potential impact of eliminating acid drainage from tailings is enormous.

Results of the tailings studies have been transferred by means of CANMET reports, by oral presentation to the International Council on Applied Mineralogy, and by submissions to scientific journals.

The study on arsenic-rich uranium tailings outlined the weathering process for these tailings and displayed the large difference from the weathering of sulphide-rich tailings.

MINERAL DRESSING

GOAL AND SCOPE:

To ensure the availability of beneficiation technology needed to enhance productivity and improve product quality from known Canadian deposits, in a technically and economically feasible manner while minimizing environmental impact.

Canada is well endowed with mineral resources and the challenge of the last decade was the need to maintain an adequate resource base for mineral supply and to increase production capacity. The challenge for survival facing the industry today is to become more efficient and consequently more competitive in world markets. In order to contend with this new situation, the objectives are to increase the productivity of existing plants and processes.

Activity is focussed in the following Major Project Areas:

1. Iron Ore Processing
2. Beneficiation of Complex and Refractory Ores
3. Energy Conservation in Industrial Minerals Processing
4. Beneficiation of Industrial Minerals

PERSONNEL:

Two Ph.D. Metallurgists
One M.Sc. Metallurgist
One M.Sc. Mineral Processing Engineer
Five B.Sc. Metallurgists
One B.Sc. Mining Engineer
One B.Sc. Chemist
One B.Sc. Geologist
Six Mineral Dressing Technologists
Three Laboratory Technicians/Tradesman

P.R.A. Andrews

B.Sc. Royal School of Mines, 1965. M.Sc. Mineral Processing Engineering, University of Melbourne, 1971. 8 years with CANMET.

Expertise in mineral processing plants and mineral processing research.

Ms. M. Boisclair

Diplôme en minéralurgie, Collège de la région d'amiante, 1985. 2 years with CANMET.

Expertise in flotation of rare earths, laboratory procedures for mineral treatment.

***W.H. Cameron**

B.Sc. Geological Sciences, Queen's University, 1973, 14 years with CANMET.

Expertise in iron ore processing, gravity separation, process control, most mineral processing operations.

R.B. Campbell

Diploma, Mineral Processing, Haleybury School of Mines, 1973. 14 years with CANMET.

Expertise in coal beneficiation and analysis.

T. Cienski

B.A. Metallurgy, Poland, 1956. 3 years with CANMET.

Expertise in mineral processing, economic layout of plants, column cell flotation, and hydrometallurgy of copper.

M.A. Cristovici

B.Eng. Mining and Metallurgy, Bucharest, 1951. 8 years with CANMET.

Expertise in basic and applied research in mineral processing, precious metals, refractory metal ores (eg. titanium) and industrial minerals.

***D.G. Feasby**	B.Sc. Metallurgical Engineering, Queen's University, 1964. M.Sc. Metallurgical Engineering, Queen's University, 1965. 6 years with CANMET. Expertise in mineral processing research, extractive metallurgy of uranium, environmental control and waste management, mineral processing plant operation.
P. Groulx	Expertise in sample handling and preparation, record keeping and data processing. 19 years with CANMET.
Ms. L. Kuehn	B.Sc. Mining Engineering, Queen's University, 1989. 1 year with CANMET. Expertise in mineral processsing plant operation, column flotation, expert systems.
J.M. Lamothe	B.Eng. Ecole Polytechnique, 1982. 7 years with CANMET. Expertise in industrial minerals processing, computer assisted processing, energy conservation.
L.V. Lacelle	18 years with CANMET. Expertise in machining and fabrication of instruments and mineral beneficiation test equipment.
G.W. Leigh	Diploma, Mineral Processing, Haleybury School of Mines, 1975. 14 years with CANMET. Expertise in gravity separation and flotation systems, batch and continuous scale.
***G.I. Mathieu**	B.A. Arts, Laval, 1956. B.Sc., Laval, Metallurgical Engineering, 1960. B.Com., Commerce, University of Ottawa, 1969. Diploma of Public Administration, Carleton University, 1972.

Expertise in coal processing, complex non-metallic and sulphide ore processing; expert in magnetic separation theory and practice. 30 years with CANMET.

D. McCarthy

Expertise in laboratory techniques of mineral processing. 18 years with CANMET.

K.S. Moon

B.Sc. Seoul National University, 1964.
M.A. Sc. Mineral Engineering, University of British Columbia, 1976.
Ph.D. Materials Science, Berkeley, 1985. 7 years with CANMET.

Expertise in surface chemistry of minerals, electrochemistry of flotation and beneficiation of sulphides and cleaning of coal.

Ms. L. Morin

Diplôme en minéralurgie, Collège de la région d'amiante, 1984. 4 years with CANMET.

Expertise in laboratory techniques for industrial minerals processing, particle size measurement.

T. Negeri

B.Sc., Mining Yugoslavia, 1978.
Ph.D., Mining Yugoslavia, 1983.
New employee.

Expertise in precious metals ore processing technology, sulphide flotation and industrial mineral processing.

P.J. Prud'homme

Diplôme en chimie, Hull Institute of Technology, 1967. 22 years with CANMET.

Expertise in laboratory techniques for industrial minerals processing research.

Ms. A. Putz

B.Sc. Metallurgical Engineering, Montana School of Mines, 1987. New employee.

Expertise in precious metals ore processing plants.

M. Raicevic — Expertise in operation, maintenance and design of all types of mineral processing equipment, from bench scale to complex pilot scale equipment. 23 years with CANMET.

V.G. Reynolds — B.Sc. Chemistry, Carleton University, 1970, 18 years with CANMET.

Expertise in analytical chemistry, x-ray fluorescence, fine particle beneficiation, photography.

FACILITIES:

This section has all the equipment necessary for wet and dry processing of metallic and industrial minerals; all types of grinding, flotation, magnetic, gravity and electrostatic separation. The latest technology in particle size measurement has been acquired, and advances in column cell flotation technology are being developed.

CAPABILITIES:

- unit process examination for all types of mineral concentration processes
- design and optimization of plant flowsheets
- continuous pilot-scale testing of processes at rates to 200 kg per hour

MAJOR PROJECTS:

1. IRON ORE PROCESSING:

OBJECTIVE:

To support the viability and competitivness of the Canadian iron ore industry by identifying and investigating methods to increase recovery, improve grade and quality of ore concentrates and pellets, reduce energy costs, improve process control and lessen environmental impact.

DESCRIPTION, INTERACTION AND IMPACT:

i) An extensive literature survey was carried out on various methods of grade control to a concentrator. As a result of this survey a contract was awarded to Geostat Systems International Inc. to implement a geostatistical grade control programme at Quebec Cartier's (Q.C.M.) Mt. Wright operation. This resulted in a marked reduction in feed fluctuations to the concentrator.

ii) A joint sampling campaign carried out by Ore Dressing and Biochemistry identified a biofouling problem in the Q.C.M. spirals which was spoiling spiral configuration which resulted in recovery loss. Once the problem was identified, corrective action was taken restoring configuration and recovery.

iii) Quebec Cartier Mining had a problem in obtaining a well-defined interface in the thickener that treats the overflows of the recycle and fine tailings cyclones. Research investigations carried out in the Ore Dressing section determined only 85 mg/t of anionic polyacrylamide flocculant improved settling rates 2-14 times and increased the amount of supernatant up to 30%. This plan was implemented by the Company.

iv) Heavy liquid studies on a series of feed size fractions to a heavy media separator were carried out. The results of these studies were converted into a series of densimetric curves which the company involved was able to use to change the S. G. of their media, resulting in an increased grade and recovery.

v) Numerous amines were tested in reverse flotation of iron ore for Q.C.M. to achieve a high grade, low-silica iron concentrate. Excellent results were obtained but the plan was never implemented as the future of the operation was uncertain at the time.

vi) A literature survey and laboratory investigations were carried out for Q.C.M. on a problem with self draining ores creating tons of sludge in the hold of vessels upon shipping. These studies are on going and appear very promising. Application to patent the methodology involved has been made.

vii) Investigations on the use of alternative binders to bentonite in the pelletizing of Iron Ore Co. of Canada concentrate were carried out. The company has since undertaken further study to implement this technology.

viii) Flotation investigations followed by high intensity magnetic separation were carried out on Wabush Mines rougher spiral tailings in an attempt to reduce the manganese in the concentrate. Although acceptable grade and recovery were obtained at the exceptionally low silica values of 0.69%, the manganese could only be lowered to 1.23%, as compared to a target grade of 1.0% set by the Company.

ix) A literature review on circuitry instrumentation and process control was completed as support of the new industry CANMET project being initially called "The Iron Ore Producers Real Time Control Investigations".

2. BENEFICIATION OF COMPLEX AND REFRACTORY ORES:

OJBECTIVE:

To develop new process and treatment methods for the beneficiation of complex and refractory ores. Many high grade and easily liberated ores are being depleted. For Canadian mining operations to remain competitive on a world market, it is necessary to develop methods to efficiently treat complex, low grade and refractory ores.

DESCRIPTION, INTERACTION AND IMPACT:

i) An investigation was carried out on the selective flocculation of tantalum ore for Tanco Mining Company. The investigations indicated that a stable suspension could be achieved at pH values higher than 10; however it appeared that an efficient separation by flocculation could not be achieved due to the low content of valuable minerals and to the complexity of the ore mineralization.

ii) Micro-bubble flotation tests were conducted on the minus 0.2 mm portion of a finely ground sulphide (copper) ore for Brunswick Mining. Although fine bubbles of < 50 um in diameter were produced there was a great deal of bubble coalescence, thus nullifying the advantage of the high surface area created by the tiny bubbles. From these experiments it was concluded that micro-bubble flotation would only be suitable for particles smaller than 5 um. This work was not continued.

iii) Investigations were carried out to attempt to make cassiterite amenable to recovery by flotation using sulphide collectors such as amyl xanthate. These investigations were carried out for Kidd Creek Mines. Two tin reduction methods were tried with results being negative. Failure of the methods were attributed to the fact that Kidd Creek cassiterite is not a semi-conductor and experiments require an elevated temperature. This work was not continued.

iv) Investigations are on-going to upgrade a tin flotation concentrate obtained by a Briquest reagent. The rougher concentrate of 0.6% Sn has been upgraded to 5% Sn. Further investigations are in progress.

v) Investigations were carried out on the Faro Deposit of Curragh Resources. The ore did not prove difficult to concentrate and acceptable lead and zinc grades and recoveries were achieved. It is believed higher lead concentrates could be attained with additional cleaning and higher zinc concentrates if the zinc rougher were reground.

vi) Tests performed on Hudson Bay Mining and Smelting Trout Lake ore yielded acceptable copper and zinc grades and recoveries. Further studies by sequestering with a chelating agent were recommended.

vii) Investigations carried out for Noranda on the Tally Pond deposit proved negative as only acceptable copper, lead and zinc grades were achieved from a few selected areas of the deposit.

viii) For the past twenty years CANMET has had an interest in column flotation. A pilot plant size, fully computerized flotation column (6.1 cm diameter X 674 cm height) has been purchased, installed and commissioned. A joint CANMET-industry-university column flotation research program is about to begin. The 3 year program will include comparitive testing of alternative spargers, testing of circuits including both columns and conventional cells, examination of alternative column designs. The total program cost will be of the order of $2M.

3. ENERGY CONSERVATION IN INDUSTRIAL MINERALS PROCESSING:

OBJECTIVE:

To increase the efficiency of energy use in the processing of industrial minerals through the identification of energy intensive unit operations, development and demonstration of improved technology and the transfer of that technology to the user industry.

DESCRIPTION:

The industrial minerals processing industry is energy intensive because of the need to fire materials at high temperature and to produce very finely divided powders from materials that are usually very hard and abrasive. A typical high energy consumer in the industrial minerals processing sector would be the cement industry, which fires raw materials to a high temperature and grinds the cement clinker product to a very fine size to provide the reactivity required for Portland cements. Another characteristic of the industrial minerals industry is the general low profitability per unit sold, which limits the research and development capability of the industry.

A multi-phased study on energy conservation in industrial minerals processing was started five years ago. The first phase examined the energy consumption in the processing of 10 different industrial minerals such as limestone, silica and mica. The second phase of the program established that particle size measurement and process monitoring methodology were both critical to reducing energy use. The last phase is the pilot scale demonstration of new **energy saving technology** in the processing of various industrial minerals.

INTERACTION:

The work has been completely **contracted out** to the industrial minerals processing and consulting industry.The transfer of the findings to the industry is progressing through seminars and personal visits by CANMET staff. A measure of the energy savings achieved to date is difficult to measure because of the general secretiveness of the industry, and the financial inability of the industry to adopt quickly new technology.

IMPACT:

A high efficiency classifier demonstrated that power savings of 25% and classifier efficiency improvement of 48% was possible in the processing of a Canadian calcite. Similar savings were demonstrated for use of high efficiency classifiers in cement grinding circuits. Extensive testing of grinding aids such as triethanolamine, acetic acid, and silicone showed that were very effective in improving the grinding performance of four industrial minerals. These levels of improvement will require full scale plant testing, but improvements in product output for each plants system will be between 10% and 100%. On line particle size measurement and programmed control of showed similar potential improvements. An extensive program on the wet milling of asbestos ores indicated no energy saving, but an overall production cost saving of 19%. This technology is being tested in a large pilot plant project.

4. BENEFICIATION OF INDUSTRIAL MINERALS:

OBJECTIVE:

To identify problems and opportunities and to develop improved methods in the processing and production of marketable industrial minerals from Canadian mineral resources.

DESCRIPTION:

The laboratory has been active for many years in the development of processing technology and in the evaluation of Canadian mineral deposits. The staff has been active in summarizing these past activities in the form of **Summary Reports**. These summary reports are organized by mineral commodity.

With the development of mineral testing facilities in the private sector, research work is becoming more of a specialty nature, such as the development of treatment technology to recycle waste fibreglass and foundry sand. A **dynamic metal separator** has been developed that will separate materials based on their conductivity.

The increasing demand for minerals as strengthening agents in composite materials is leading to an expanding market for high aspect materials such as wollastonite, muscovite mica, and graphite. Beneficiation technology is being developed for these minerals. **New potash beneficiation technology** is being examined that, if successful, will radically change the requirements for disposal of waste salt tailings. At present these water soluble tailings are deposited on surface at the rate of 10 million tonnes per year.

INTERACTION:

All projects are being contracted from or are done in cooperation with industrial clients and Provincial Government agencies who are interested in promoting development of industrial mineral deposits in Canada. Because the industry is highly dependent on information, the laboratory spends considerable effort in transferring to the industry non-confidential information through personal contact and the dissemination of written reports.

IMPACT:

The **Summary Reports** have been described by an industry spokesman as a "gold mine" of information. The development of beneficiation technology will most likely lead to the exploitation of one or more Canadian deposits. The **dynamic metal separator** has an immediate application in the recycling for use of a hazardous waste at an aluminum producer, and will undoubtedly have economic application elsewhere such as the recovery of values from municipal waste. New potash beneficiation technology will dramatically reduce the requirement for disposing soluble salts on the surface; waste management savings of the order of $20 million per year are predicted.

COMPUTER-AIDED MINERAL PROCESSING

GOAL AND SCOPE:

To provide the technology transfer necessary to improve the recovery and/or value of minerals from the processing of Canadian Ores through the application of computer techniques.

Activity is focussed in the following Major Project areas:

1. Numerical applications in mineral processing
2. Expert systems in mineral processing

PERSONNEL:

One DSc in Extractive Metallurgy
One MSc in Physics
One Bsc in Physics
One BSc in Mining Engineering

Below are listed the names, qualifications and expertise of all technical and scientific personnel working in this area. An asterisk before the name indicates that a detailed Curriculum Vitae is included in Book Three.

Magella Bilodeau	B.Sc Mining Engineering, option Mineral Processing, Laval University. 4 years with CANMET. Responsible for microcomputer software engineering developments. Has developed the first FORTRAN/MS-DOS interfaces allowing the development of interactive and user-friendly data entry and display modules in all CAMP programs.
Edward Ter Heijden	BSc Physics, Carleton University, 1971. 1 year with CANMET. Responsible for advanced mathematical methods of flowsheet simulation and liberation modelling. Is currently developing a new release of a general flowsheet simulator and a unit calibrator.

Daniel Laguitton

Doctorat ès Sciences, 1974, Laval University, Quebec; Diplôme de Docteur en Sciences Physiques, 1970, Université de Rennes, France; Diplôme d'études approfondies en Chimie Minérale, 1969, Université de Rennes, France; Diplôme D'Ingénieur Chimiste, 1968, Ecole Nationale Supérieure de Chimie de Rennes, France. 11 years with CANMET.

Mathematical modelling and computer simulation of mineral processes, software engineering, technology transfer to industry. Also carried out successful research projects on electron microprobe quantitative analysis and non-destructive analysis of thin films by X-ray fluorescence.

Jean Leung

MSc Physics, University of Waterloo, 1972. 11 years with CANMET.

Responsible for material balance software developments and statistical analysis since 1985. Also active in expert system applications. Monitored and contributed to the latest on-line expert system prototype at Kidd Creek Mines.

FACILITIES:

The group has access to microcomputers and software. If required, the mineral processing laboratory equipment of CANMET could be used. However, for model development and calibration most experimental data has come, in the past, from industrial locations through contractual agreements.

CAPABILITIES:

- sampling methodology
- material balance adjustments
- modelling and model calibration
- flowsheet simulation
- expert system development

MAJOR PROJECTS:

1. NUMERICAL APPLICATIONS IN MINERAL PROCESSING

OBJECTIVE:

To develop and improve numerical methods conducive to more efficient mineral processing tasks.

DESCRIPTION:

The SPOC project (Simulated Processing of Ore and Coal) which began in 1980, is aimed at developing a series of computer programs for process evaluation and optimization and transferring such methodology to industry. The first release of these programs, intended for mainframe computers, was announced in 1984. Since that time, the programs have undergone continuous improvements to respond to user needs and to make them fully compatible with Personal Computers. The current version features all new user friendly tools expected of modern computer software.

INTERACTION:

The SPOC project originally consisted of a series of joint tasks undertaken by universities (e.g., Laval, McGill, Univ. of Alberta, UBC) and industry (e.g., Noranda). Since 1980, 24 research contracts were completed, involving 6 Canadian universities and 9 companies, for a total value of over $0.5M. Since then interaction has been focussed more on users (see below).

IMPACT:

Direct savings of a quarter of a million dollars per year have been reported by Matabi Mines (Noranda) after applying the SPOC methodology. EXXON Minerals credits SPOC for software used in one of their comminution studies of fossil fuel shale. CANMET's release of MATBAL received top marks and recommandations in a published review of material balance packages by independent scientists at The University of Minnesota. As a spin-off of SPOC, CANMET has now established a team devoted to Computer Aided Mineral Processing and distributing the latest microcomputer versions of the various programs produced during the SPOC project. This software has gained worldwide recognition: since January 1989, 263 clients enquired about the CAMP software. Among them, 36 purchased software for a total of $80K. The orders are distributed in 10 countries as follows: Canada 19, USA 6, U.K. 1, France 1, Australia 4, Spain 1, Netherlands 1, Sweden 1, Mexico 1, Chile 1.

2. EXPERT SYSTEMS IN MINERAL PROCESSING

OBJECTIVE:

To assist the Canadian mineral industry in integrating AI applications by identifying and developing prototype expert systems and ensuring their implementation in plant practice.

DESCRIPTION:

This activity is the logical extension of our projects in numerical simulation. Initially, CANMET's role was as a catalyst between knowledge engineers and domain experts/users. CANMET now serves as an advisor in the application of existing shells and has been active, through various transfer mechanisms, in developing an awareness of the power of Expert Systems within the Canadian mineral industry.

INTERACTION:

Three joint projects have been completed from 1986 to 1989 in contracts of a total value of about $0.5M, equally funded by CANMET and industrial partners.

Grinding circuit expert:

CANMET, Canada Cement Lafarge, UNISYS and Laval University cooperated in developing a trouble-shooting system for clinker grinding circuits, using the KEE/EXPLORER environment.

Zinc plant expert:

CANMET, Lavalin and Canadian Electrolytic Zinc cooperated in developing this expert system for operator assistance in making solution pumping decisions in order to optimize acid distribution between the leaching, cleaning and electrolysis halls. Personal Consultant and a Compaq 386 were used to support this prototype.

On-line data validation expert:

CANMET and Kidd Creek Mines cooperated in developing this expert system for data validation in the automatic process control strategy used in the Cu and Zn flotation circuits at Kidd Creek Mines.

IMPACT:

In all three cases, a direct experience of knowledge engineering and other aspects of expert system development provided all partners with invaluable insight in mastering this new technology. CANMET acquired a leadership in this field that was quickly transferred to industry in numerous seminars, workshops and consultations. The Kidd-Creek on-line system constitutes a unique example of its kind in North America and a special workshop in October 1989 attracted over 30 participants.

PYROMETALLURGY

GOAL AND SCOPE:

The objective of the work in Pyrometallurgy in EML/MSL is to investigate and develop new and improved processes, and to enhance current processes, for the extraction of metals from their ores and concentrates by pyrometallurgical methods and for the examination of noxious gas emissions during combustion phenomena.

Pyrometallurgy encompasses projects in air pollution control, plasma reactors, SO_2 capture in fluidized bed combustion, non-ferrous smelter technology and chemical sensor development.

Activity is focussed in the following Major Project Areas:

1. Air Pollution Control
2. Non-ferrous Smelter Technology
3. Sorbent Characterization for Fluidized Bed Combustion
4. Sensor Development

PERSONNEL:

Four Ph.D. pyrometallurgists
One M.Sc. pyrometallurgist
One M.Sc. engineer
Two B.Sc. physical scientists
Two technologists

Below are listed the names, qualifications, and expertise of all technical and scientific personnel working in this area. An asterisk before the name indicates that a detailed Curiculum Vitae is included in Book Three.

A.A. Dubreuil	B.Sc. (chem.), M.Sc.A. (met. eng.), Ph.D. (met. eng.). Fourteen years of research experience involving development of real-time chemical sensors and forming and sintering of various ceramics for various applications. One half year with CANMET.

Research scientist in development of sensors to measure concentrations of species such as SO_3-SO_2 and AsH_3 in gases as well as metal ion species in liquid metals, mattes and slags; perform cost recovery projects.

W.J.S. Craigen

B.Sc., Chemical Engineering (1951), Queens University; P.Eng
18 years with CANMET.

Thirty-five years experience in the development and evaluation of mineral processing systems, convering all aspects of hydrometallurgical and pyrometallurgical processing of ores and concentrates to produce refined metallic or non-metallic products.

Smelting/refining of base metal sulphides. Hydrometallurgical processing of base metal sulphides, uranimum & precious metals. Chloride metallurgy for non-ferrous metals. Techno-economic evaluations of mineral processing systems, including flow-sheet development and engineering design.

C.A. Hamer

B.Eng. (met.), M.Sc. (met. eng.), P. Eng. Twenty-four years in production, research and development in industry and government. Fourteen years with CANMET.

Research scientist in extractive metallurgy in both hydrometallurgy and pyrometallurgy, e.g., non-bauxite alumina extraction; limestone evaluation for absorption of SO_2 in fluidized bed combustion; implementation of new CANMET Project Management System; scientific authority on cost-shared contracts; perform cost recovery projects.

J.B. Kearns

Gr. 12 (Ont.), 1st year chem. (Carleton). Thirty-four years of bench, pilot and on-site research and development in government and Crown Corporation laboratories in the fields of pyrometallurgy and hydrometallurgy. Sixteen years with CANMET.

Senior technologist in extractive metallurgy using a wide range of equipment in both pyrometallurgy and hydrometallurgy.

D.T. Liang

B.A.Sc. (chem. eng.), M.A.Sc. (chem. eng.), Ph.D. candidate (chem. eng.). Eleven years of research experience involving combustion and high temperature processes. Six years with CANMET.

Engineer in fluidized bed technology and mathmatical modelling; research in pyrometallurgy, pollution abatement, design and engineering of pilot plants; scientific authority on cost-shared contracts; perform cost recovery projects.

S.A. Mikhail

B.Sc. (chem. and phys.), M.Sc. (fer. met.), Dr.Eng. (inorg. chem.), Ph.D. (inorg. chem.). Twenty-eight years of research and development experience in high temperature inorganic and physical chemistry related to the metallurgical processing of products of the Canadian minerals industry. Twelve years with CANMET.

Research scientist in thermal analysis, including differential thermal, thermogravimetric and effluent gas analysis by Fourier transform IR spectroscopy. Solid-gas reactions such as reduction, oxidation, sulphation and chlorination. Matte-slag chemistry, molten salts, kinetics of thermal decomposition and oxidation of arsenide minerals. Development of thermal analytical methods for use in monitoring the efficiency of fluidized bed coal combustors and for advanced ceramics.

*** J.M. Skeaff**

B.A.Sc. (met. eng.), M.A.Sc. (met. & mat. sci.), Ph.D. (met. & mat. sci.). Twenty-five years of research experience in government and university in the fields of pyrometallurgy and hydrometallurgy. Fifteen years with CANMET.

Head of MSL's Pyrometallurgy Section. Expertise in pyrometallurgy, high temperature processing, thermochemistry.

A.-M. Turcotte

D.E.C. (1980) CEGEP de l'Outaouais. Experience involving operation of thermal analysis equipment. Four years with CANMET.

Experimental work in high temperature chemistry including slag/matte studies and thermal analysis, gas chromatography, optical spectroscopy including preparation of samples, IR spectroscopy and analytical chemistry.

A.H. Webster

B.A. (chem.), M.A. (phys. chem.), Ph.D. (met.). Thirty-six years of research experience in high temperature physical and inorganic chemistry related to the metallurgical processing of products of the Canadian minerals industry. Thirty-two years with CANMET/Mines Branch.

Head of EML's Physical Chemistry Section, with resposibilites for research and development in high temperature chemistry, applied statistics, electrochemistry and surface chemistry. Investigation of the distribution of minor consituents such as Ni, Co, Mo and Se between slag, matte and metal phases, as well as recovery of minor valuable constituents from slags. High temperature kinetics and phase diagram studies related to pyrometallurgy.

L.J. Wilson

B.Sc. (chem.). Eleven years of research experience involving pyrometallurgical processes. Eleven years with CANMET.

Thermal analysis of the oxidation of arsenides and methods for the removal of toxic emissions from smelter gases; computer applications to pyrometallurgical processes and thermal analysis.

FACILITIES:

Pyrometallurgy has a wide range of research and processing equipment at its disposal: differential thermal and thermogravimetric analysis including Fourier transform IR spectroscopic analysis of gaseous products, recirculating fluidized bed, three-phase AC arc furnace, plasma furnace, AC multi-frequency impedance bridge, electric and gas-fired rotary kilns, high temperature and controlled atmosphere furnaces.

CAPABILITIES:

Thermal analysis, determination of thermochemical properties of arsenates and arsenides, phase diagram and high temperature studies related to pyrometallurgical systems, roasting and smelting studies, lab and mini-plant process development.

MAJOR PROJECTS:

1. **AIR POLLUTION CONTROL:**

OBJECTIVE:

To evaluate and where feasible to develop effective and acceptable methods for the monitoring and control of noxious elements encountered in Canadian pyrometallurgical processes.

DESCRIPTION:

Stricter environmental regulations on arsenic-bearing materials and increasingly higher levels of arsenic in custom feeds to smelters have combined to cause a significant degree of interest and concern over high temperature arsenic chemistry.

Thermochemistry and thermal analysis are used as the investigative tools to develop data presently lacking for arsenides and arsenates and the compounds of other group VB and VIB elements, as well as methods for eliminating SO_2 in smelter off-gases.

To date, thermochemical studies for the compounds NiAs, $Ni_{11}As_8$, Ni_5As_2 and $FeAsO_4$ have been completed and preliminary data for $Pb_3As_2O_8$ have been obtained. Studies of the oxidation and thermal dissociation of synthetic skutterudite [$CoAs_3$], safflorite [$CoAs_2$] and of skutterudite [$(Co,Fe,Ni)As_3$] by differential thermal analysis and thermogravimetry have been completed.

INTERACTION:

A CANMET scientist has completed a secondment with the Smelting Technology Department of the Noranda Technology Centre; the study continues at CANMET as a joint project. If successful, the project may lead to a new process for the removal of arsenic from a process stream. Other documented support comes from industry, government and university research organizations in Canada, the U.S. and the U.K.

IMPACT:

The data resulting from these studies can be used to predict stable condensed phases and gas compositions occurring under roasting or other pyrometallurgical conditions and thereby lead to processes for controlling emissions of arsenic-bearing compounds. This would enable Canadian smelters to process feeds containing higher than currently possible levels of arsenic.

2. NON-FERROUS SMELTER TECHNOLOGY:

OBJECTIVE:

To assist the Canadian non-ferrous smelting industry in the development and implementaion of new and improved technologies for smelter modernization, which will substantially reduce gaseous (SO_2) emissions and losses of valuable metals while increasing the industry's productivity and international competitiveness.

DESCRIPTION:

Canada's non-ferrous smelter industry is a major international producer of non-ferrous metals as well as a major emitter of acid rain-generating SO_2.

Some of the 20 projects included here are:

1. flash converting of bulk Ni/Cu concentrate.
2. recovery of Au and Ag from zinc pressure leach (ZPL) residues.
3. DC plasma arc furnace.
4. technical and economic evaluation of Hudson Bay Mining and Smelting (HBMS) modernization.
5. improvements in smelter practice such as the recovery of nickel and cobalt from slag by extraction into an iron sulphide matte formed by fusion of pyrrhotite; development of a clean smelting process for highly roasted nickel-copper calcines with improved metal recovery; and investigation of the possibility of reducing selenium levels in blister copper by extraction into molten copper oxide.
6. development of tin recovery flowsheet for client.

INTERACTION:

1. Flash Converting of Bulk Ni/Cu Concentrates: CANMET scientists interact with the Dept. of Industry, Science and Technology (DIST), INCO Sudbury and INCO Port Colbourne.

2. Gold-silver recovery from ZPL residues: joint CANMET-HBMS project

3. DC Plasma Arc Furnace: investigation of the production of utility nickel at INCO Port Colbourne, resulting in interactions with NSERC, the Ontario Ministry of Energy, and INCO scientists and engineers.

4. HBMS Smelter modernization: CANMET scientists have worked closely with HBMS personnel in developing a technical and economic assessment of the alternatives for the HBMS smelter modernization.

5. improvements in smelter practice: close cooperation between CANMET, Falconbridge and Kidd scientists to investigate methods for attaining the objectives of study.

6. CANMET has forwarded a proposed flow sheet and process development plan to the client.

IMPACT:

1. DIST-INCO funding of technological improvements to reduce SO_2 emisions at INCO.

2. precious metal recovery technology for implementation as part of smelter modernization at HBMS.

3. technology which could be implemented as part of the INCO Port Colbourne modernization program.

4. delineation of environmental and economic benefits of HBMS smelter modernization.

5. changes in operation of Falconbridge smelter to reduce SO_2 emissions while maintaining efficient operation. However, investigation showed that there was little possibility of producing a low-selenium copper metal by the extraction of selenium into copper oxide.

6. should the development work prove successful, the possibility exists that a commercial tin operation will be commissioned.

3. SORBENT CHARACTERIZATION FOR FLUIDIZED BED COMBUSTION:

OBJECTIVE:

To develop techniques for measuring sorbent capacity for SO_2 removal and to develop mathematical models for predicting sorbent performance in circulating fluidized bed combustors in order to optimize limestone performance.

DESCRIPTION:

A novel technique for evaluating fine limestone samples for SO_2 absorption capacity is being further developed to include samples for lime-with-fuel injection. A high temperature quartz fluidized bed test facility which can be used for the study of denitrification as well as desulphurization is currently under construction. The project is an integral part of the Energy Research Program's fluidized bed combustion project.

INTERACTION:

CANMET scientists have considerable interaction with power utilities, e.g., New Brunswick Power Commission, Nova Scotia Power Corporation as well as consultants and engineering companies, e.g., Monenco, W. Shaw, D. Winship, etc. to evaluate limestones for use as sulphur dioxide sorbents in combustors.

IMPACT:

Costs of desulphurizing limestones are significant so that any improvements in effiencies are welcomed. The limestones used in fluidized bed units at Summerside, PEI, and at Chatham, NB, were chosen, in part, based on CANMET evaluations. CANMET is being consulted regarding the best limestone for the proposed 150 MWe unit in Nova Scotia. The CANMET fluidized bed reactor apparatus and technique have been duplicated by other member organizations in the IEA Atmospheric Fluidized Bed Combustion Agreement. CANMET's work in this field is recognized in an Electric Power Research Institute sponsored study as being one of six major programs world-wide.

4. **SENSOR DEVELOPMENT:**

OBJECTIVE:

To investigate the development, from demonstration in principle to commercial application, of ceramic-based sensors for important species such as SO_2-SO_3, As_2O_3 in gases and metal ions in matte, slag and metal phases which occur in pyrometallurgical processes.

DESCRIPTION:

Opportunities exist for the development and application of ceramic-based, high temperature chemical sensors and structures to improved environmental and process control.

Projects included here are:

PbO sensor for lead blast furnace slags,
SO_3-SO_2 sensor,
As_2O_3-AsH_3 sensor,
F_2-HF sensor,
Na, Li and Mg sensors for molten aluminum,
elemental sulphur sensor for reducing atmospheres,
improved structure for ozone generation (cost recovery project).

INTERACTION:

Dielectrics for ozone generation:

CANMET scientists interact with Systèmes Ozonics and Ecole Polytechnique in Montréal.

PbO sensor for lead blast furnace slags:

This has been planned as a joint project with Brunswick Mining and Smelting of New Brunswick, Cominco and Nordion International (AECL).

Arsine (AsH_3) sensor:

CANMET scientists interact with scientists from Ecole Polytechnique in Montréal, RTZ in Bristol, U.K., and instrument manufacturers Instantel of Kanata and MDA Scientific of Chicago.

Elemental sulphur sensor for reducing atmospheres:

CANMET scientists interact with scientists from Ecole Polytechnique in Montréal.

IMPACT:

The sensors developed under this project can be expected to yield improved process and environmental control. For instance, a PbO sensor would enable lead blast furnace operators to adjust feed and air flow rates to minimize PbO-in-slag losses. Again, a fast response AsH_3 detector would be an improvement over slower acting conventionally available detectors. The project has a considerable potential for cost recovery and intellectual property development.

HYDROMETALLURGY

GOAL AND SCOPE:

To develop and evaluate improved and new hydrometallurgical processes for the efficient extraction of metals from ores, concentrates and residues; to develop technology for the economic recovery of valuable by-products; to ensure the environmental viability of all existing or new hydrometallurgical processes.

Comprehensive studies and understanding of the chemistry of metals in solution involve dissolution, precipitation, solution speciation, electrochemistry, ion-exchange and solvent extraction. A broad industrial and academic clientele is served whose interests are in base metals, gold and precious metals, rarer metals, by-products, and the environment.

Activity is focussed in the following Major Project areas:

1. Copper Refining Group
2. Canadian Zinc Processors
3. Gold
4. Chloride Metallurgy
5. Mineral Electrochemistry

PERSONNEL:

Seven Ph.D. Hydrometallurgists
Three Ph.D. Electrochemists
One Ph.D. Mineralogist
One M.Sc. Hydrometallurgist
Four B.Sc. Hydrometallurgists
Ten Technologists

Below are listed the names, qualifications and areas of expertise of all technical and scientific personnel working in this area. An asterisk before the name indicates that a detailed Curriculum Vitae is included in Book Three.

***Syed M. Ahmed**

B.Sc. (Honours), Mysore, 1954
M.Sc., Mysore, 1956
Ph.D., Sask., Saskatoon, 1962

Twenty-three years experience at CANMET.
Electrochemistry and photoelectrochemistry of semiconductors;
Chemical physics of semiconductors - optical and electrical properties, photo and electroluminescence, magnetron sputtering of metal semiconductor surfaces;
Energy conversion, hydrogen energy, solar to chemical energy conversion on semiconductors;
Photocatalytic reactions on semiconductors;
Interface chemistry and colloid chemistry;
Flotation of oxide and sulphide minerals - electrochemistry and interface chemistry of flotation;
Electroosmotic dewatering of clays and tailings.

P.L. Bédard

Diplôme, CEGEP Outaouais, 1976
Technique Chimie Analytique

Eight years experience at CANMET.
10 years experience in pilot plant operation;
4 years experience with autoclave;
Communication between different instruments;
FTIR instrument;
A.A. instrument;
Computer programming.

Douglas Bell

B.A.Sc. (1956), University of Toronto
D.I.C. (1960), Imperial College of Science & Technology
Ph.D. (1960), University of London

Four years at CANMET as a technology coordinator, administrator and advisor in the field of metallurgy. Experience in mineral commodity studies, policy

formulation and drafting of legislation. Eight years experience in process engineering and design for metallurgical processes and five years experience in metallurgical research in processing of coke and in metallurgical reactions.

J.M. Brannen

St. Pats College, 1st year Science
Carleton University, Engineering, 1 year; total 2 years
Algonquin College (E.O.I.T.), 6 courses - chemistry and electronics

Thirty years experience at CANMET. Under the direction of a Research Scientist, designs, develops and constructs novel bench and pilot plant scale electro-chemical cells, conducts non-routine experimental techniques for purification of electrolytes, electrowinning of metals and electrodissolution of minerals using aqueous and fused salt electrolytes.

T.T. Chen

Ph.D., 1971, Cornell University
M.Sc., 1969, Carleton University
B.Sc., 1964, National Taiwan University

Fifteen years experience at CANMET. Applied mineralogist with experience in sulphide mineralogy, pyrometallurgy, hydrometallurgy and electron microscopy. Expertise in the application of various mineralogical methods including electron microscopy to assess hydrometallurgical processes, particularly the electrorefining of copper and the processing of zinc. Considerable experience in sulphosalt mineralogy, copper anode slimes and zinc leach residues.

Guy Deschênes

M.Sc. (Metall. Eng.) 1985, Laval University
B.Sc. (Metall. Eng.) 1981, Laval University

Four years with CANMET

Thiourea leaching of gold and recovery of gold from thiourea solutions;
Hydrometallurgy of gold including testing of activated carbon;
General electrochemistry and electrochemistry of the anodic dissolution of lead sulphide;
Process control and optimization of gold mill performance;
Production experience in pyrometallurgy of copper.

Orlando Dinardo B.Sc., University of Ottawa

Fifteen years experience at CANMET. Process development for electrolytic silver refining;
Solution characterization;
Percolation and pressure leaching;
Behaviour of impurities in jarosite and hematite precipitation;
Bacterial oxidation of thiosalts.

***J.E. Dutrizac** Ph.D., 1967, University of Toronto
M.A.Sc., 1964, University of Toronto
B.A.Sc., 1963, University of Toronto

Twenty-one years experience at CANMET. Extractive metallurgist with experience in both hydrometallurgy and pyrometallurgy as well as a continuing involvement in the field of applied mineralogy. Expertise in the ferric ion leaching of sulphides, and in the related field of iron precipitation and control. Work has involved jarosite precipitation and hematite formation. Considerable experience in the processing of zinc, the electrorefining of copper and the hydrometallurgical treatment of lead. Considerable involvement in the treatment of metallurgical effluents to control arsenic and thiosalts. Some experience and

expertise in the processing of zirconium, titanium and magnesium.

Wesley Griffith

Chemical Engineering Technologist Diploma, 1986, Algonquin College

Two years experience at CANMET involving sample preparation such as crushing, grinding and sizing of various metal ores and concentrates. Carried out bench scale cyanide, thiourea and acid leach tests. Worked on pretreatment of refractory gold concentrates with microwave irradiation, pressure oxidation in autoclaves and low temperature roasting in muffle furnaces. Carried out chemical analysis which involves volumetric determination of cyanides, chlorides, etc. and atomic absorption determinations. Experience in various computer softwater programs.

Kazi E. Haque

Ph.D. (Chem.), 1968, University of Ottawa

Fifteen years experience with CANMET and six in academia in research and development in the fields of pure and applied chemistry and extractive metallurgy. Process development for radioactive ores, gold ores-both free milling and refractory-rare earths, zirconium and beryllium ores; removal of contaminants from mill effluents as well as from a contaminated soil and industrial dust; development of new processing technologies for metals recovery from solution by hydride reduction; processing of minerals by applying microwave energy such as the reactivation of CIP spent carbon with microwave.

D.J. Hardy

Diploma in Technology (Chemical Engineering Technology), 1974, Algonguin College, Ottawa
Completed 2 years of B.Sc. at Carleton University, Ottawa (continuing)

Fifteen years experience at CANMET.
Assemble and operate leaching apparatus for kinetic studies;
Metal analysis and data reduction;
Conduct synthesis experiments for various mineral species;
Design new or modify existing apparatus or equipment to suit the experiment.

Peter D. Kondos

B.Sc. (Engineering, Mining, Mineral Processing and Metallurgy), 1980, National Technical University, Athens, Greece
M.Sc. (Mining Engineering), 1983, McGill University
Ph.D. (Metallurgical Engineering), 1988, McGill University

One year at CANMET in the area of statistical modelling and solution chemistry; modelling/optimization leaching systems; pressure leaching; microwave applications; mineral industry effluent treatment.

Daniel Laforest

Geology Engineering Technician Program Diploma, 1980, Cambrian College of Applied Arts and Technology

Three years experience at CANMET in the areas of gold ore leaching, process development of the refractory gold ores, microwave activation of CIP spent carbon, leaching of oxide ores, FTIR spectroscopy, analytical methods for metal analysis from leach liquors and microwave applications in pyrometallurgy and hydrometallurgy.

R.J.C. MacDonald

B.Sc. (Chem.) 1956, St. F.X. University

Twenty-three years experience at CANMET in the areas of mineral synthesis, leaching kinetics and chemistry, technology transfer and program management. Ten years experience with industry and government in the areas of ferro-alloys, stainless steel, zirconium-based alloys and corrosion testing.

Head of the Extractive Metallurgy Laboratory's Leaching Section with responsibilities for: research and development in bench and pilot scale leaching of various metal sulphides, precious metals, rare earth oxide ores, concentrates and residues; aqueous chloride metallurgy including the FCL leach process; investigation of various leach alternatives for the treatment of refractory gold ores; application of microwave technology to minerals technology; optimization of gold extraction processes through instrumentation, data acquisition modelling and process control.

***D.J. MacKinnon**

Ph.D. - 1969, University of Ottawa
M.Sc. - 1964, St. Francis Xavier University
B.Sc. - 1963, St. Francis Xavier University

Twenty years experience at CANMET. Conducts research and experimental developmental work in solution purification and metal recovery by cementation reactions, the application of electrochemical techniques for the recovery of metals from sulphide minerals and the recovery of metals from aqueous and fused salt electrolytes by electrowinning. Recent studies have included research and developmental work on zinc

electrowinning from aqueous chloride electrolyte as well as fundamental studies on zinc electrowinning from sulphate electrolyte, the electrochemical leaching of sulphide minerals and on the cementation of copper and silver from chloride solutions.

***Ronald Molnar**

Ph.D. (Metall.) 1980, University of London, Imperial College, Royal School of Mines
DIC 1980, University of London, Imperial College
B.Eng. (Metall. Eng.) 1972, McGill University
Eight years with CANMET

Supervision of solution purification section (3 professionals and 4 technicians);
Planning of research, budgeting and allocation of section fiscal and personnel resources, evaluation and appraisal, hiring and related administrative matters;
Solvent extraction of metals from aqueous solutions including bench scale testing, design, construction and operation of pilot plants and operation of specialized equipment (both in-house and at remote locations);
Purification of metallurgical solutions;
Solvent-in-pulp extraction testing;
Cost recovery proposal preparation with negotiation of agreements;
Scientific authority on outside contracts and technical advice to colleagues;
Occupational health and safety;
Transportation of dangerous goods;
Assistant editor, Hydrometallurgy.

Raymond Morrison

B.Sc. (University of British Columbia, 1975)
Ph.D. (University of British Columbia, 1980)

Nine years experience at CANMET.
Fundamental and applied studies in electrochemistry and electrometallurgy pertaining mainly to zinc processing, copper electrorefining and gold recovery in commercial operations;
Basic and applied chemistry of leaching and cementation reactions usually with respect to silver chemistry in leaching and chloride metallurgy cementation.

Pierre Prud'homme

Certificat en Chimie Industrielle 1968, Institut de Technologie Laval, Montréal
Twenty-one years with CANMET

Solvent extraction bench scale and pilot plant testing (in-house and at remote locations);
Ion exchange bench scale and pilot plant testing;
Assembly and operation of specialized equipment for ion exchange and solvent extraction testing;
Leaching of minerals on bench and pilot scale (various technologies);
Sample preparation for metallurgical testing including crushing, grinding, screening, splitting, etc.;
Pyrometallurgical testing for extractive metallurgy;
General hydrometallurgical testing procedures;
Occupational health and safety.

Patricio Riveros

Ph.D. (Metall. Eng.) 1985, Queen's University
M.Sc. (Chem. Eng.) 1978, University of Bradford, England
B.Sc.(Chemistry) 1974, University of Chile
Three years with CANMET

Ion exchange recovery of metals including gold, gallium and PGM as well as base metals such as copper;

Experimental work in resin development and fundamentals of ion exchange recovery of metals;
Aspects of solvent extraction of metals such as gold, PGM and others including fundamentals of relevant chemistry, selection of reagents and bench scale testing;
General aqueous inorganic chemistry;
Participation in projects on purification of Zn and copper electrolytes, extraction of Ga from Bayer liquors, arsenic elimination in leach solutions, cyanide and cyano-complex removal from effluents.

David Y. Shimano

B.Sc. (Chem.) 1982, Concordia University
Diploma: Metallurgical Engineering Technology 1968, Ryerson

Seven years experience at CANMET and ten years in industry in hydrometallurgical processing including research and development at bench mini-plant and plant scale;
Chloride hydrometallurgical treatment of concentrates including leaching, cementation, crystallization and the regeneration of lixiviants at both bench and pilot plant scale.
Uranium processing including leaching, solvent extraction, continuous ion exchange and effluent treatment at both bench, pilot plant and plant scale;
Zirconium processing including leaching, solvent extraction, crystallization and fluid bed polishing at plant scale.

Madona Skaff

B.Sc. (Hons. Biol.) 1980, Carleton University
Six years with CANMET

Pilot plant operations for coal liquefaction and fuel processing;
Solid and liquid fuels analysis and testing;
Metals solvent extraction bench scale testing;
Biochemical testing of blood enzyme activity;
Plant tissue culture and embryogenesis;
Electron microscopy and related techniques;
Chemical analysis by microscopy, wet chemical and instrumental techniques.

K. Gie Tan

Ph.D. (University of Ottawa, 1977) - physical chemistry
Dipl. Chem. (T.H. Aachen, 1973)- inorganic chemistry

Four years experience at CANMET.
Solution and solids characterization;
Leaching and purification reactions;
Process development work;
Mass balance calculations and computer modelling;
Analytical chemistry;
Physical chemistry;
Technical chemistry and engineering.

Bruce Taylor

Fifteen years with CANMET.

Chemical analysis of aqueous and organic solutions;
Set-up and operation of tailings disposal simulation testing (lysimeters);
Pressure leaching of minerals;
Sample preparation for metallurgical testing including crushing, grinding, screening, splitting, etc.;
General hydrometallurgical testing procedures.

Gerald Wallingford Diploma in Mining Technology (3 years), 1965, Haileybury School of Mines

Twenty three years experience at CANMET in ore dressing (crushing, grinding, sizing), atmospheric and pressure leaching, bacterial leaching, ion exchange, solvent extraction, liquid-solid separation (clarification, flocculation, centrifugation, thickening), spray drying, furnace work (muffles, rotary kilns, blast furnace), atomic absorption analyses, liquid-gas chromatography analyses, precipitation work and microwave irradiation of concentrates.

Carl J. Weatherell B.Sc. (Honours Co-op)
University of Waterloo
1984

Five years experience at CANMET.
Develop methods for the analysis and speciation of trace elements in hydrometallurgical solutions by High Performance Liquid Chromatography;
Resolve analytical problems encountered with industrial zinc and copper refining products through joint CANMET-industry research;
Assist in the preparation and certification of copper anode and copper anode slimes reference materials;
Explore the removal of iron from zinc processing solutions.

En Wei Wong Medical Doctorate 1961, Sun Yat Sen Memorial Medical College, Canton, P.R. China
Eleven years with CANMET.

Solvent extraction bench scale and pilot plant testing (in-house and at remote locations);
Ion exchange testing;

General inorganic chemistry of aqueous metallic solutions as related to solvent extraction;
Precipitation and cementation chemistry;
Operation of specialized equipment for solvent extraction and ion exchange.

FACILITIES:

A wide range of facilities is available to support the hydrometallurgical activities underway; these include:

- ore crushing and grinding facilities

- flotation and column flotation apparatus

- gravity and magnetic separation equipment

- various types of leaching apparatus, including ring-disk electrodes, autoclaves, oil baths, etc.; pressure leaching facilities including several medium size autoclaves

- microwave facilities for applications in metallurgical processes

- solution purification apparatus including continuous SX-IX mini plants, various types of SX contacting equipment including pulse columns and centrifugal contactors, cementation cells and precipitation apparatus

- liquid/solid separation as well as CIP and RIP technology

- full-height pilot cells as well as potentiostats of several types, including devices for cyclic voltammetry and ring-disk electrode studies

- SEM-EDX and electron microprobe analytical capabilities to examine anodes, anode slimes and various reaction products

- UV spectrophotometry, Fourier transform IR spectroscopy, AA spectroscopy, ion chromatography, new chemical determination methods

- metallurgical process development, liquid-solid separations, multiphase contracting reactors, effluent treatment, chemical synthesis and physical chemistry; various mini plants and small pilot plants

- autosampler, autodilutor, process controller, computer interfacing, data processing, data base management, computer programming, experimental design and systems modelling.

CAPABILITIES:

- Mineralogical characterization of copper anodes, anode slimes and various zinc intermediate products; the mineralogical data are related to plant operating conditions

- Leaching of various materials on a mini plant scale and a fundamental interpretation of the leaching data; special emphasis on gold leaching and on the ferric ion leaching of sulphides

- Electrochemical studies related to metal deposition or electrorefining including polarization studies, scanning voltammetry and pilot size electrolytic processing. Deposit characterization complements the electrochemical studies

- Solution property determinations including solubilities, conductivities and analytical procedure development

- Iron precipitation techniques, definition of precipitation arameters, impurity deportment and product characterization; work is done at both ambient and elevated pressures

- Characterization of cementation reactions, the definition of the controlling parameters and a fundamental explanation of the cementation reactions

- A broad knowledge base has been developed in chloride metallurgy that includes leaching, purification and metal recovery options; this knowledge base has been projected to the development of chloride processing routes for various ores and concentrates
- Considerable expertise has been developed in SX-IX techniques and their application to solution purification and metal recovery from a wide range of processing solutions. This includes the selection of

reagents and of required operating conditions, design and operation of continuous mini-pilot plants to verify the experimental parameters, and determination of data for full-scale plant design

- Expertise in the milling of ores and their upgrading by flotation methods or physical separation techniques

- A considerable knowledge base has been established for the environmental control of various milling and processing effluents including thiosalts, cyanide-bearing effluents and effluent treatment sludges

- As required, analytical procedures have been developed to identify specific constituents in hydrometallurgical solutions or to devise rapid on-line analytical techniques

- A broad knowledge base has been developed in gold metallurgy, with special emphasis on refractory ores, that includes leaching with cyanide and non-cyanide media, purification and recovery options, optimization, modelling and process control.

MAJOR PROJECTS:

1. COPPER REFINING GROUP

OBJECTIVE:

In co-operation with the Canadian copper industry to develop by 1990 improved technologies for the characterization, deposition, control and processing of impurities in electrolytic copper refining.

DESCRIPTION:

Canada is a major producer of copper concentrates, and a large percentage of the concentrates are processed domestically at the seven copper or copper/nickel smelters located across the country. Copper anodes typically contain >99% Cu together with objectionable impurities such as Se, Te and As as well as valuable by-products such as Au, Ag and Pt. Although the copper refining process is over 125 years old, many parts of the process are not thoroughly understood and several persistent problems remain. All refineries experience anode passivation problems and the causes of the passivation are not well understood. Because of the increased impurity loadings, anode slimes processing and copper electrolyte purification

are becoming increasingly more complex and difficult. Metal value recovery from the anode slimes is a concern and cathode quality remains of prime importance for the sale of the copper product.

In an effort to address the above concerns, CANMET, in close co-operation with the copper industry, is seeking to develop improved technologies for copper electrorefining and to expand the knowledge base for the electrorefining process, the characterization of the anode slimes and the purification of the copper electrolyte. CANMET's contribution is in the form of processes, reports, new techniques, etc. which are made available to the industry. CANMET also serves as a "consultant" to industry to help resolve technical problems as they arise.

INTERACTION:

The project involves several industrial participants as well as various interested academics. All the participants function as a technical working group. In addition, representatives from the copper refining companies meet periodically as a "management sub-committee" to set priorities, ensure widespread co-operation and to establish mechanisms of technology transfer. Because the representatives of the "management sub-committee" are also members of the larger group, they can function with a minimum of additional documentation and without a separate formal organizational structure.

IMPACT:

Development and adoption of better slimes control strategies will allow increased throughput in existing refineries with associated cost reductions for energy and manpower. High purity copper could increase annual metal sales by $2-10 million for some companies. Better impurity control would permit the smelting of a wider range of concentrates, thereby assuring concentrate supplies for existing facilities. Increased by-product recoveries and reduced by-product costs could also result.

2. CANADIAN ZINC PROCESSORS

OBJECTIVE:

In co-operation with the Canadian zinc industry, to develop by 1993, improved technologies for zinc leaching, iron rejection, impurity control, by-product recovery and zinc

electrolysis; to improve the knowledge base of the extractive metallurgy of zinc.

DESCRIPTION:

Canada is the world's largest supplier of zinc concentrates and is also a major producer of refined zinc metal. Although the zinc industry is well established, many challenges remain. Improved milling and flotation practices are needed to increase zinc recoveries and to reject unwanted impurities where mineralogically possible. Impurity deportment during roasting and leaching is important both for impurity control and by-product recovery. Iron control is critical, and improved technologies for producing environmentally stable iron precipitates are needed. Zinc electrolysis is an energy intensive process, and better solution purification methods are required to ensure the continuous production of zinc at high energy efficiency. In this regard, the role of organics in zinc electrolysis requires detailed investigation. If Canada's zinc industry is to continue to flourish, improved technologies and better process understanding are required. To address the above concerns, CANMET, in close co-operation with the Canadian zinc industry, is developing improved technologies for zinc leaching, iron rejection, impurity control/recovery and zinc electrolysis, and is also expanding the knowledge base of the extractive metallurgy of zinc. CANMET's contribution will be in the form of processes, reports, new techniques, etc. which will be made available to the industry. CANMET will also serve as a "consultant" to industry to help resolve technical problems as they arise.

INTERACTION:

The project involves all the Canadian zinc producers as well as various interested academics. All the participants function as a technical working group. In addition, representatives of the zinc producers meet periodically as a "management sub-committee" to set priorities, guarantee widespread co-operation and to establish mechanisms of technology transfer. Because the representatives of the "management sub-committee" are also members of the larger group, they function with a minimum of additional documentation and without a separate formal organizational structure. There is a strong indirect linkage with the international Jarosite R&D Group which is looking specifically at the iron disposal problem.

IMPACT:

Development of improved methods for iron control/removal and electrolyte purification will allow increased throughput with associated cost reductions for energy and manpower. A better understanding of the role of organics and metallic impurities in zinc electrolysis and the development of a control methodology for the addition of organics to the electrolyte will maintain high efficiency tank house operation and minimize plant upsets. Superior methods of recovering Ag, Au and other trace elements from zinc leach residues will increase the profitability of zinc plants.

3. GOLD

OBJECTIVES:

To characterize the mineralogy of gold in refractory ores in order to relate the physical and chemical properties to mineral processing and metal extraction. To investigate alternate leaching processes applicable to refractory gold ores. To optimize existing and to develop new methods of gold recovery from pregnant solutions.

The main focus of the CANMET Gold Project is on better understanding of the nature of refractory ores and on improved or new technologies which will allow the milling and treatment of such ores economically. Environmental acceptability of ore treatment and extraction methods is a very important consideration in the implementation of new technology. The research includes alternatives to roasting, cyanidation and carbon adsorption.

DESCRIPTION:

With the strong economic performance of gold over the past several years, Canadian production has expanded significantly. Although the principal process for the recovery of gold has been in place for many years, parts of the process are still not fully understood and problems remain. As well, the industry has been slow to change. For example the CIP process has been in Canada for less than a decade. New process steps are now being introduced and alternatives are being proposed. CANMET has undertaken to keep abreast of developments and to investigate areas for potential process improvements. The complexity of ore bodies and low grades often encountered have limited the full exploitation of gold-bearing deposits. The development of methods for achieving higher extraction and

recovery can have significant economic benefits. Recovery of fine gold from placer and lode deposits presents a challenge. Treatment of refractory and complex gold ores such as arsenical ores is a particular problem if roasting is to be avoided.

CANMET in close cooperation with the industry contributes to expansion of the gold technology data base through processes, reports and new techniques which are made available to the industry. CANMET also serves as consultant to the industry when requested.

Aspects of current gold work involve the following:

- mineralogical investigations
- thiourea leaching of gold ores and recovery from solution
- gold recovery from refractory gold concentrates and ores
- recovery of gold with ion-exchange and solvent extraction
- optimization, modelling and process control
- northern placer testing laboratory, in Yellowknife, Yukon

INTERACTION:

CANMET has been successful in forming a Technical Advisory Committee to advise and assist CANMET in its gold related work. This group, consisting of representatives from gold operations across the country, meets semi-annually to review projects underway and to advise on industry needs for further research and development.

IMPACT:

Development of improved or new technologies which are directed toward increasing overall recovery and throughput; the lowering of costs also can have a significant impact on the economic viability of many gold operations. This is especially true in the case of refractory gold and increasingly lower ore grade deposits.

4. CHLORIDE METALLURGY:

OBJECTIVES:

To develop and evaluate viable chloride metallurgical processes which will achieve the goals of metal recoveries above 90% and the elimination of SO_2 emissions by yielding elemental sulphur or stable sulphides from bulk sulphide

concentrates. To investigate various applications of chloride metallurgy within the non-ferrous metals industry.

DESCRIPTION:

The complexity of some sulphide ore bodies, as exemplified by those of New Brunswick, limits the recovery of saleable products using existing technology. Improved recoveries can be obtained by producing a bulk concentrate, but such concentrates are not amenable to conventional processing. CANMET has developed a chloride process for the treatment of such complex concentrates. A basic flowsheet using ferric chloride leaching, zinc solvent extraction, Cu-Ag recovery by cementation, $PbCl_2$ crystallization and zinc chloride electrolysis was tested. A preliminary economic evaluation suggested the ferric chloride route to be competitive with other technologies. Current work focusses on the refinement of the initial mass balances, economic evaluation, and the elaboration of flowsheet detail such as Cd recovery.

Chloride leaching systems offer many potential and long-term benefits for the processing of the common metals together with the generation of elemental sulphur. Because of the potential benefits of this type of technology, CANMET continues to investigate the underlying principles of chloride metallurgy as related to leaching, solution purification by SX-IX or cementation, and metal recovery by electrolysis or other means. Because the electrolytic production of copper from chloride media is of interest to several companies, test work embraces product morphology, impurity deportment, cell design, and removal of the copper particulates from the cell. The comparative use of Cu_2Se versus Cu for Ag removal from chloride leach liquors forms part of this investigation.

INTERACTION

Investigation and evaluation of chloride processes for the treatment of complex sulphides has been carried out both in-house and under contract. A basic flowsheet based on a two-stage chloride leach process has largely been confirmed.

Preliminary evaluation data indicate that the ferric chloride leach process is technically and economically viable. Presently, CANMET is seeking an industrial partner before proceeding to a continuous pilot plant operation.

As well as interaction with domestic base metal producers, liaison with the international scientific and industrial community is strengthened through linkages such as the cooperative program on complex sulphides between CANMET and the EEC, linkages to the U.S. Bureau of Mines, and linkages to Australia's base metal industry. In the latter case an agreement has been reached with an Australian firm to promote further development of CANMET's ferric chloride leach process.

5. MINERAL ELECTROCHEMISTRY

OBJECTIVES:

To investigate the roles of electrochemical processes and of semiconducting and other solid state properties of sulphide minerals in relation to leaching of ores and concentrates, flotation processes, and control of acid generation in mill tailings. A related objective is to develop photocatalysts and processes for destruction of pollutants in water.

DESCRIPTION:

Many reactions at semiconducting mineral-aqueous solution interfaces are electrochemical in nature. Hence an understanding of the electrochemical phenomena and the role of semiconducting properties at such interfaces should lead to means of controlling leaching reactions and of inhibiting oxidation and acid generation in sulphide tailings. The relationship between the energy levels of the semiconducting minerals and the electrochemical potentials of the redox reagents at mineral-solution interfaces is important in controlling the charge transfer and dissolution processes; hence investigations in this area are required.

INTERACTION:

Under an agreement with Noranda Technology Centre, investigations are being conducted in MSL on electrochemical and surface chemical inhibition of acid generation due to oxidation of pyrite, pyrrhotite and sulphide-containing tailings.

A similar agreement has also been reached with Nulite Corporation for the development of a semiconducting TiO_2

film for the removal of pollutants such as CN^-, $S_2O_3^{2-}$ and chloroorganics and PCBs. Some cost recovery work has also been carried out for this company. Similar sponsorship for a new electrochemical method for H_2O_2 production, which has been developed in our laboratory, is being sought.

IMPACT:

Alleviation of environmental problems associated with reactive acid-generating tailings, through development of new methods for inhibiting oxidation and acid generation in sulphide tailings. Alleviation of water pollution by development of methods for destruction of organic pollutants such as PCBs in water. Possible increased efficiency in hydrometallurgical circuits from the development of methods for controlling selectivity in leaching reactions.

BIOTECHNOLOGY

GOAL AND SCOPE:

To identify, quantify, test and apply biological phenomena to improve processes for the recovery of metal values, to enhance the recovery of fossil fuels, and to reduce the environmental impact of industrial operations in these fields to acceptable levels.

Activity is focussed in the following Major Project areas.

1. Bacterial leaching of sulphide ores
2. Biological metal removal from dilute solutions
3. Biological treatment of industrial effluents
4. Biological treatment of acid mine drainage
5. Networking

PERSONNEL:

Two Ph.D. Microbiologists
One M.Sc. Microbiologist
One B.A.Sc. Bioengineer
Two technicians

Below are listed the names, qualifications and expertise of all technical and scientific personnel working in this area. An asterisk before the name indicates that a detailed Curriculum Vitae is included in Book Three.

G. Béchard

B.Sc. Microbiology, Laval University, 1986.
M.Sc. Applied Microbiology, Inst. Armand Frappier, Université du Québec, 1989.
Ph.D. Candidate, Carleton University.
1 year with CANMET.

Expertise in anaerobic microbiology, anaerobic degradation of aromatic compounds, microbial ecology and cellulose degradation.

C. Chalykoff

B.Sc. Biochemistry, University of Ottawa, 1968.
B.Sc. Honors Biology, Carleton University, 1977.
3 years with CANMET.

Expertise in microbial physiology, general microbiology, microbial ecology and biotechnological process development.

***W.D. Gould**

B.Sc. Chemistry, University of Manitoba, 1965.
M.Sc. Soil Microbiology, University of Alberta, 1970.
Ph.D. Soil Microbiology, University of Alberta, 1976.
3 years with CANMET.

Expertise in soil microbiology, inorganic and organic chemistry, industrial microbiology, process development.

***R.G.L. McCready**

B.Sc. Pharmacy, University of Alberta, 1961.
M.Sc. Microbiology, University of Alberta, 1963.
Ph.D. Microbial Metabolism and Physiology, The University of Calgary, 1973.
7 years with CANMET.

Expertise in microbial metabolism and physiology, applied and industrial microbiology, process development.

S. Rajan

Diploma in Medical Technology, University of Madras, 1972.
Diploma in Hydrometallurgy, B.C.I.T., Vancouver, 1977.
7 years with CANMET.

Expertise in aerobic and anaerobic microbiology and biotechnological process development.

J. Salley

Diploma in Biochemical Technology, Algonquin College, 1977.
B.A.Sc. Chemical Engineering, University of Ottawa, 1983.
4 years with CANMET.
Expertise in bioengineering and biotechnological process development.

FACILITIES:

The section has all the equipment for general microbiological research; autoclaves, controlled temperature shakers, controlled temperature incubators, a laminar flow hood. Specialized equipment includes large scale bacterial leaching columns, rotary biological contactors (RBC's).

CAPABILITIES:

- isolation and identification of bacteria,
- laboratory, small pilot scale and large column bacterial leaching of ores.
- laboratory and small pilot scale process development.

MAJOR PROJECTS:

1. BACTERIAL LEACHING OF SULPHIDE ORES:

OBJECTIVE:

To develop an economically viable biohydrometallurgical process to extract and recover secondary metal values from sulphide ores, specifically those portions of mineral deposits which are left underground for mine support or which are below cut-off grade for conventional mining.

DESCRIPTION:

Projects included in this program are the commercial bacterial leaching and recovery of uranium at Denison Mines, Elliott Lake, Ontario; pilot plant leaching of a complex sulphide ore for the recovery of copper and zinc at the University of Manitoba; an SEM study on the sequential leaching of metals from a complex sulphide ore; and a heavy isotope labelling study to determine the source of oxygen during bacterial metal sulphide oxidation.

INTERACTION:

Leaching of Uranium:

- with the leaching group at Denison Mines and research personnel from Laurentian University and the University of Waterloo.

Leaching of Copper and Zinc:

- with Hudson Bay Mining and Smelting Inc, the University of Manitoba and the Manitoba Department of Mines and Energy.

SEM study on sequential leaching:

This is a cooperative study between members of the Biotechnology Section and the Mineralogy Section of CANMET. The ore was supplied by Hudson Bay Mining and Smelting Inc.

Oxygen source during leaching:

This is a cooperative study between the Biotechnology Section of CANMET and the Department of Physics, The University of Calgary.

IMPACT:

The bacterial leaching of Uranium has been commercialized and 10-15% of Denison's annual uranium production is derived from the bacterial leaching process.

If the current pilot plant study is successful, HBM&S plan to spend $1-2,000,000 in development costs and hope to recover $20,000,000 worth of Cu and Zn over the next 10 years.

The results of the SEM study will be published and transferred to HBM&S and the University of Manitoba as they will be applicable to the leaching program at HBM&S.

The oxygen source study is a basic study which will clarify conflicting reports in the literature and the results may be applicable to both bacterial leaching of metals as well as prevention of acid mine drainage (AMD) generation within sulphidic tailings.

2. BIOLOGICAL METAL REMOVAL FROM DILUTE SOLUTIONS:

OBJECTIVE:

To develop biological processes for the recovery of low levels of metal ions from dilute solutions such as acidic mine drainage, mill and smelter effluents or dilute process streams.

DESCRIPTION:

Two biological process developments are currently being investigated: the adsorption and recovery of uranium by immobilized fungal biomass; the bioreduction of selenite and selenate from acidic smelter effluents.

INTERACTION:

A research consortia composed of CANMET, Ortech International, McMaster University, Denison Mines and Acres, Davy McKee Engineering Ltd. has been formed to develop the uranium bioadsorption process. The biorecovery of selenium from effluents involved CANMET, Kidd Creek Mines, Ortech International and CMS Rotodisk Ltd.

IMPACT:

If the uranium bioadsorption process is successful Denison Mines, and possibly Rio Algom Mines, could use the process to concentrate the pregnant liquors from the bacterial leaching operations or Denison could use the process to remove residual uranium from the feed to their yttrium plant.

If Kidd Creek Mine or a company with a smelter of similar throughput were to implement the patented process they could recover metallic selenium worth about $800,000/yr.

3. BIOLOGICAL TREATMENT OF INDUSTRIAL EFFLUENTS:

OBJECTIVE:

To develop biological processes to remove environmental pollutants such as heavy metals, organics, inorganics from industrial effluents in an environmentally safe manner.

DESCRIPTION:

Projects under this program include: biodegradation of organics in tailings recycle water for NIOBEC Mines and biodegradation of an organic pollutant for a major mining company; biodegradation of deicing fluids and urea for Transport Canada. (Because of the Biotechnology expertise, Transport Canada requested its help in solving the environmental problem caused by deicing fluids).

INTERACTION:

Organic Degradation:

CANMET, NIOBEC Mines and McGill University have a joint program to develop the process.

Organic Pollutant:

The major patented process development was by CANMET, Carleton University and the major mining company. CANMET has received assistance in identification of the new organism from Health and Welfare Canada, Agriculture Canada and the University of Calgary.

Deicing fluids and urea:

CANMET and the Airports Authority Group, Transport Canada have developed a rotating biological contactor based process which is currently being patented.

IMPACT:

Currently, since implementing recycle of their tailings water, NIOBEC's flotation reagent consumption has increased by $300,000/year. Preliminary results indicate that the offending organics can be removed.

The major mining company has assessed a variety of options to deal with their pollutant and have decided to build a pilot plant at their facilities to test the CANMET/Carleton process.

Transport Canada currently has to pay various cities a sewage surcharge for the release of these compounds into the storm sewers.

4. BIOLOGICAL TREATMENT OF ACID MINE DRAINAGE:

OBJECTIVE:

To develop a self-sustaining, biological ecosystem to remove metal pollutants, sulphate and mitigate the pH of acid mine drainage (AMD).

DESCRIPTION:

Over the past five years the Biotechnology Program has supported numerous contractors in their assessment and development of biological processes to mitigate acid mine drainage. Currently, CANMET is developing a biological process for the treatment of small acidic drainage streams.

The CANMET process is currently being field-tested at the Halifax International Airport, where pyritic shales are producing acidic drainage.

INTERACTION:

CANMET has contracted out about $350,000 over the past five years on biological treatment of acid mine drainage. The contractors include: Boojum Research Ltd, P. Lane and Associates Ltd. and Ecosystems Technologies Ltd.

CANMET has developed, in the laboratory, a biological process for the mitigation of AMD and is currently field-testing the concept in cooperation with Transport Canada at the Halifax International Airport.

IMPACT:

If the field test is successful and the process is applied to other drainage streams at the airport, Transport Canada will be able to decommission their water treatment plant at a savings of about $600,000/yr.

5. NETWORKING:

OBJECTIVE:

On a continuing basis to maintain and expand a network to improve the interaction and communication between the research community and the Canadian Mineral and Fossil Fuels Industries, and to improve the availability and accessibility of relevant information.

DESCRIPTION:

CANMET acts as the secretariat for the BIOMINET Network and publishes four quarterly newsletters, organizes and publishes the Proceedings of the Annual Meeting, conducts training seminars and workshops and acts as a liaison between the industry and the researchers.

INTERACTION:

The BIOMINET Network has grown from forty members in the fall of 1983 to 619 currently. Greater than half of the members are from the mineral or fossil fuels industries, 20% from private research organizations, 15% from Universities and the remainder from government laboratories.

IMPACT:

BIOMINET holds annual meetings to expose industry to the latest research results, produces a quarterly newsletter, has presented the workshop entitled "Basic Microbiology for the Mineral and Fossil Fuels Industries" in four different geographic locations and organized information seminars on government funding for industrial research and process development. Through BIOMINET, CANMET was requested to co-sponsor the 9 th. International Symposium on Biohydro-metallurgy in Jackson Hole, Wyoming, August 13-18, 1989.

ENVIRONMENT

GOAL AND SCOPE:

To undertake research in the fields of air pollution control, water pollution control and the management of mine tailings and waste rock and to balance these research activities with the needs of industry and current and future environmental regulations. To work with Energy Mines and Resources and Environment Canada in the formulation of environmental policy, standards and regulations.

Activity is focussed in the following Major Project areas:

1. Mine Environment Neutral Drainage Program
2. Cyanide Recovery From Gold Mill Process Solutions Using the AVR Process
3. Air Pollution Control
4. Water Pollution Control
5. Acid Mine Drainage Predictive Technologies
6. Evaluation of Methods to Stabilize Tailings and Waste Rock

PERSONNEL:

One M. Eng. Environmental/Chemical Engineer
One M. A. Sc. Chemical Engineering
One B. Sc. Chemistry (part time)
One Technician

(Others involved in Environment are listed in their respective program areas.)

Below are listed the names, qualifications and expertise of technical and scientific personnel working in this area. An asterisk before the name indicates that a detailed Curriculum Vitae is included in Book Three.

Michel P. Filion — B.A.Sc. Chemical Engineering, University of Waterloo, Waterloo, Ontario, Canada, 1975.

M.Eng., Environmental Engineering, McMaster University Hamilton, Ontario, Canada, 1980.

Thirteen years of experience in the mining and mineral processing industry, with responsibilities in environmental management, planning, licensing, plant and waste decommissioning, environmental research, auditing and environmental impact preparation. 1.5 years with CANMET.

Gordon M. Ritcey

B.Sc.(Chem.), Dalhousie University.

Hydrometallurgy of uranium and thorium, rare earths, base metals and rare and precious metals. Solvent extraction of metals, equipment selection, operation and scale-up. Hydrometallurgy of base metals and platinum group metals, particularly in chloride solutions. Environmental issues relating to hydrometallurgical extraction processes and tailings disposal and management. 21 years with CANMET.

Vern M. McNamara

1949 B.Eng.(Chemical), University of Saskatchewan
1954 M.A.Sc.(Chem.Eng.), University of Toronto

Three and one-half years process R&D, International Nickel Research Labs,Copper Cliff, Ontario.

Thirty-five years as a research scientist at CANMET. Major projects included:

-uranium processing and purification involving leaching, ion exchange, solvent extraction;

-development of chemical technology for production of ultra pure electronic ceramic materials required for deep ocean piezo-electric sensors;

-development of a high temperature chlorination process for application to lead-zinc sulphide ores;

-development of the AVR process. CANMET consultant for cyanide pollution control technologies.

Leonard E. Carter — High School Graduate

Twenty-four years at CANMET in a widely varied capacity involving equipment assembly and operation in the fields of hydrometallurgy (chemical leaching, ion exchange, AVR bench and pilot process development, bacteria-assisted leaching) and in pyrometallurgy (chlorination procedures developed at bench and pilot scale).

FACILITIES:

Lysimeters, columns for deep water simulation studies, small pilot plant for cyanide control, variety of process equipment and wide range of analytical support facilities.

CAPABILITIES:

Laboratory studies in chemistry, biotechnology, and mineralogy. Coordination of national effort in developing mathematical modelling and tailings management technologies.

MAJOR PROJECTS:

1. MINE ENVIRONMENT NEUTRAL DRAINAGE (MEND) PROGRAM

OBJECTIVES:

To provide a comprehensive scientific, technical and economical basis for the mining industry and governmental agencies to predict, with confidence, the long-term management requirements for reactive tailings and waste rock, and

To establish techniques that will enable the operation and abandonment of acid-generating tailings and waste rock disposal areas in a predictable, affordable, timely and environmentally acceptable manner.

DESCRIPTION: .

A comprehensive, five year, $ 12.5 million research program was defined in 1988. Research will be undertaken in four principal areas: Prediction (Analytical Methods and Computer Modelling), Prevention and Control technologies, Passive and Upgraded Chemical Treatment technology and Monitoring. Technology Transfer and International Liaison activities are included in the research plan.

Nineteen research projects were initiated in 1988/89 for a total financial commitment of $ 3.2 million, as of May 1989.

INTERACTION:

MEND is a cooperative effort involving the Canadian mining industry, five provincial governments and the federal government. A Board of Directors, Management Committee and six technical committees were formed during 1988 to direct the research activities. In total, four federal government departments, sixteen mining companies (including the Mining Association of Canada and the Mineral Technology Council of Canada) and ten provincial government departments are involved.

Cooperative arrangements have been made with the United States, Australia and Sweden to participate as corresponding members in the program. Complimentary research is being undertaken in these countries and research results will be shared. Memorandums of Understanding are being prepared.

IMPACT:

About 15,000 hectares of acid-generating mine wastes have been identified at operating mine sites in Canada. This quantity may double during the next 20 years. Rehabilitation of these sites could cost more than $ 3 billion during the next 20 years, a cost unacceptably high to the mining industry if it is to remain competitive. Sites which are the responsibility of the Crown may cost up to $2 billion to rehabilitate and solutions to acid mine drainage are therefore of significant interest to the provinces and the federal government.

The site rehabilitation cost estimates are based on unproven, expensive technologies. MEND has been designed to demonstrate these and other technologies and to develop cost saving measures for the industry, while at the same time protecting the receiving environment. The mining industry will not meet the Canadian mandate of sustainable development unless MEND is a success.

2. CYANIDE RECOVERY FROM GOLD MILL PROCESS SOLUTIONS USING THE AVR PROCESS

OBJECTIVES:

The Acidisfication-Volatilization-Reneutralization technology, which is currently presented for licensing, enables processing of a gold mill barren solution to attain several desirable results, namely:

- to increase the percentage of water recycling within the gold mill circuit. The ideal objective is zero discharge to the environment;
- to achieve the maximum recovery of the cyanide component of the barren solution in a reusable reagent form;
- to eliminate the environmental hazard of cyanide and base metal entry to the watershed, as stipulated in environmental regulations for plant effluents;
- to isolate most of the base metals, particularly copper, as a recoverable concentrate;
- to achieve a return on investment sufficient to write off capital costs within a realistic time frame;
- to present a treatment system which will involve simple and reliable process control, via pH and flow-volume automation;
- to utilize only inexpensive, non-toxic reagents (H_2SO_4 and lime).

DESCRIPTION:

The gold milling industry discharges large volumes of water containing appreciable quantities of metallocyanide species, as well as unassociated cyanide. The compounds are toxic and must be destroyed, immobilized, or recovered. Currently the industry utilizes cyanide destruction techniques, with resultant high reagent costs and no payback. Furthermore, base metal, reactive sludges are created and discharged into natural holding areas.
CANMET's AVR process will recover cyanide for reuse in the mill and will concentrate the base metals for subsequent reprocessing. An R.O.I. will offset capital costs in 5 years or less. Sulphuric acid and lime are the only major reagents. No pollutants are formed in the process.

INTERACTION:

- in-house techno-economic feasibility testing is performed for clients;
- strong liaison with Environment Canada;
- major contracting from industry will be achieved via a licensing agreement with an engineering firm or a consortium.

IMPACT:

The technology will ultimately ensure a major recovery of gold mill waste components (cyanide, Cu, Ni, Zn). Developing legislation (e.g., Ontario's Misa program) will increasingly demand improved techniques for the treatment of gold mill waste water. AVR application is essential for the 1990's in regard to effluent and sludge control. Water conservation can then be maximized. This process opens "windows" for future locked-cycle technical advances such as pollution control for cyanidation pulps and the recovery of cyanide from the thiocyanate component of gold mill barren.

3. AIR POLLUTION CONTROL:

(Research in this field is conducted by the pyrometallurgy group. Please refer to the information submitted by that group.)

4. WATER POLLUTION CONTROL:

OBJECTIVES:

To establish technology for the control of water pollution and to meet the standards set by regulatory agencies for the mining and processing of minerals by:

- developing technology which will eventually lead to zero discharge of contaminants and recycle of all process water
- developing more efficient processes to recover heavy metals directly from effluents. This may include electrochemical, oxidation-reduction processes, ion exchange, and biological processes
- developing and implementing methods to minimize metal release at source
- evaluating and implementing means to maximize the recycle of sludges to smelters and refineries
- developing and/or evaluating methods of sludge dewatering for disposal volume minimization.

DESCRIPTION:

The processing of ores and concentrates generates large volumes of wastewater which generally requires treatment prior to discharge. Dissolved contaminants in process water can include cyanides, heavy metals and acidity to name a few. In order to remove these contaminants, the industry installed over the past decade numerous facilities to treat wastewater with lime, producing purified water and sludges containing the contaminants.

Studies conducted by Gionet, Mellor, Liebich Associates during 1985 to 1988 for the Mineral Sciences Laboratories of CANMET showed that current disposal methods may be inadequate, and sludges already disposed may require further treatment. These findings, combined with the increasingly stricter hazardous waste regulations justify the existence of a vigorous research program.

INTERACTION:

The project involves in-house work; liaison with Environment Canada and the U.S. Environmental Protection Agency. Liaison with industry is mainly through the MEND program or on a contract basis.

IMPACT:

Development of technically and economically viable methods for dealing with effluent and sludge control in the mineral processing industry will be of prime importance over the next decade. The continued viability of processing operations will depend on successfully addressing this problem.

5. ACID MINE DRAINAGE PREDICTIVE TECHNOLOGIES:

OBJECTIVE:

To test various conditions of tailings and waste rock weathering, under controlled conditions, in order to provide predictions of effluent quality, migration patterns, acid production, disposal techniques and cover designs for operation, decommissioning and shut-down phases of mining operations.

DESCRIPTION:

Lysimeter Studies: A large number of simulated weathering tests have been carried out, ranging in size from a kilogram to 11 tonnes. Accelerated weathering, based on accelerated simulated rainfall of 5-10 times the actual at the particular mining site have been carried out on various tailings under several test parameters. Tailings have included uranium and various base metal sulphides. After initial research, a method of examination has been adopted which includes mineralogical and chemical analyses of cores, porosity, permeability, effect of freeze-thaw, effluent and water chemical analyses, analysis of salts resulting from upward pressures, bacterial effects, Eh-pH relationships, and seepage vs runoff quality and quantity.

Acid Prediction Methods: About 11 methods to predict acid generation (static and kinetic) have been examined, with lysimeters being one of the kinetic tests. Various types of tailings (low and high sulphides) were examined. Three methods, including lysimeters, will be the subject of ongoing prediction research. A handbook of the various tests methods will be issued.

INTERACTION:

The lysimeter test procedures are now being used in many countries and by several mining companies. All mining companies and government agencies are interested in having a proven reliable technique for predicting the formation of acid drainage.

IMPACT:

The ability to predict, in a suitable time frame, the probability of occurrence of acid mine drainage at proposed and existing mine sites is of significance to environmental regulatory agencies and mining companies. The design and management of waste rock, tailings, open pits and underground mines is dependent on whether the sites are net acid producers. This knowledge can have a serious impact on the economics of potential ore bodies.

6. EVALUATION OF METHODS TO STABILIZE TAILINGS AND WASTE ROCK:

OBJECTIVE:

To evaluate methods of stabilizing tailings and waste rock sites using various covers including: organic materials, rigid matrixes and water.

DESCRIPTION:

Organic Materials: Waste material from a mining municipality (wood, paper, garbage, sewage) could be used to produce compost, which then could be used towards the soil cover requirements for a tailings area. A conceptual plant was designed and a program carried out. Wetland bogs were also tested for application to tailings since compost production could be expensive.

Rigid Matrices: Various known stabilization procedures, using concrete or bitumen based methods were investigated. Most methods did not stand-up to freeze-thaw cycling and of those investigated, the bitumen process was the best, but very expensive. The use of inorganic polymers mixed with the tailings showed superior resistance to weathering.

Water Covers: About 30 feet of water were placed over 0.25 tonnes of tailings in two 2 foot diameter columns. Data indicate that for low sulphides (2%) there appears to be no problem. However, on the high-sulphide weathered tailings (92%), the pH of the overlying waters remained near pH 4.

INTERACTION:

The MEND program has been selected as the vehicle for promoting continued research in stabilizing waste rock and tailings.

IMPACT:

Practical methods of preventing acid mine drainage have yet to be demonstrated in the laboratory or in the field. The technologies described above have shown promise, but research must continue.

CONCRETE TECHNOLOGY

GOAL AND SCOPE:

To develop and transfer the technology for improved cementitious materials with greater fitness for purpose (improved properties, greater durability in aggressive environments, reduced cost and energy inputs). The work also includes the development of test methods for determining fitness for purpose. Technology transfer through conferences and workshops in a major theme as is contributing to the development of national and international standards.

Activity is focussed in the following major project areas:

1. Supplementary Cementing Materials
2. Alkali-Aggregate Reactivity
3. Concrete for Offshore Structures
4. Mine Backfill

PERSONNEL:

One D.D.L. (Hon.) Civil Engineer
One Ph.D. Chemical Engineer
One Ph.D. Petrographer
Two M.Sc. Civil Engineers
One B.E. Civil Engineer
One B.Sc. Technologist
Two C.E.T. Technologists
One Visiting Ph.D. Scientist

Below are listed the names, qualifications and expertise of all technical and scientific personnel working in this area. An asterisk before the name indicates that a detailed Curriculum Vitae is included in Book Three.

Alain Bilodeau

Baccalauré en sciences appliquées (génie civil) à l'université Laval, 1981.
Etudes en économique à l'université Laval, 1982-1983.
Etudes de deuxième cycle, Maîtrise en ingénierie (génie civil) Université de Sherbrooke. Spécialisation en matériaux principalement béton. Sous la supervision du professeur P. -C. Aitcin. 4 years with CANMET.

Expertise utilisation de cendres volantes, fumées de silice et de laitiers dans le béton. Durabilité du béton face à l'environnement canadien. Développement du béton à haute résistance. Béton avec fibres.

Gordon D. Brearley

Certified Engineering Technologist. 14 years with CANMET.

In performing investigations related to concrete technology, and preparing and disseminating information on technology transfer.

Georges G. Carette

B.Sc., Laval University, 1966. 23 years with CANMET.

Expertise in use of fly ash, slag, silica fume and other mineral by-products in concrete/system optimization and applications. Durability of concrete in Canadian environments. Performance of concrete in sea waters. High-strength performance concrete. Non-destructive testing of concrete.

Raymond Chevrier

Technician diplomas in Architectural Drafting and Construction Engineering. 8 years with CANMET.

In performing laboratory investigations in concrete technology.

Designing equipment for grading of coarse and fine aggregates for laboratory use.

Preparing audiovisual material for conferences.

Esther Douglas

B.Sc. (Chemical Engineering), University of the Litoral, Santa Fe, Argentina, 1957.
Graduate Student, Institut National Polytechnique de Toulouse, Toulouse, France, 1971-1972.
Doctor of Philosophy (Ph.D.) Department of Civil Engineering and Applied Mechanics, McGill University, 1978. 7 years with CANMET.

Expertise in characterization, properties and utilization of ferrous and non-ferrous slags for concrete and for mine backfill. Conduction calorimetry of portland cement pastes and other binders. Concrete from waste of fluidized bed combustion operations. Alkali activation of blast-furnace slags. Statistical models for prediction of compressive strength of mortars in ternary systems.

***V. Mohan Malhotra**

D.D.L. (Honorary) 1984, University of Dundee, Scotland
B.E. (Civil) 1957, University of Western Australia
B.Sc. 1951, University of Delhi. 28 years with CANMET.

Specialist in concrete technology with emphasis on: Long-term durability of concrete, NDT, utilization of supplementary cementing materials, high strength lightweight and normal weight concretes, specialized concretes for offshore structures, use of fly ash, blast-furnace slag, silica fume and natural pozzolans, alkali aggregate reactions in concrete and supplementary cementing materials for mine backfill.

Kerry E. Painter	B.Sc. (University of Carleton). 22 years with CANMET. Diploma in Civil Eng. Technology (Algonquin College, Ottawa) In performing investigations relating to durability of concrete, performance of concrete at high temperature, and non-destructive testing of concrete.
Vasanthy Sivasundaram	B.Sc.(Honours) in Engineering, University of Sri Lanka, 1977. M.Sc. in Engineering, Massachusetts Institute of Technology, 1982. 4 years with CANMET. Expertise in mechanical properties, durability aspects, and non-destructive evaluation of concrete; development of concretes incorporating supplementary cementing materials.
J.A. Soles	B.A.Sc. Geology, University of British Columbia M.Sc. Geology, University of British Columbia Ph.D. Geology, McGill University 30 years at CANMET Expertise in petrology of concrete, and of building materials.
Visiting Scientist - Mohamad Al-Asali	B.Eng. (Civil) 1968 University of Mosul, Iraq M.Sc. (Soils and Structures) 1977 University of Mosul, Iraq Ph.D. (Concrete Technology) 1987 University of Sheffield, UK 2 years at CANMET. Specialist in alkali-aggregate reactivity, particularly accelerated test methods.

FACILITIES:

The Section has all the equipment for research in aggregate,

cement and concrete technology. Principal items of equipment include, non-destructive testing equipment, several freezing and thawing units, large capacity machines to determine mechanical properties of concrete, water permeability and chloride permeability apparatus, mercury porosimeter, conduction calorimeter, creep jigs, abrasion test equipment, microscopic facilities to perform air-void analysis, large concrete mixers and associate aggregate preparation equipment, large heating ovens up to 60°C. and walk-in humidity chambers, large temperature and humidity curing room.

CAPABILITIES:

- to carry out characterization of cementitious materials,
- to perform durability studies on aggregate mortars and concretes,
- to perform accelerated tests for alkali-aggregate reactivity,
- to conduct abrasion, permeability, porosity and conduction calorimetry studies on mortars and concretes,
- to evaluate integrity of concrete by NDT materials.

MAJOR PROJECTS:

1. **SUPPLEMENTARY CEMENTING MATERIALS**

OBJECTIVE:

To develop data on mechanical and elastic properties and durability of portland cement concrete incorporating up to 65% less energy intensive materials, such as granulated blast-furnace (B.F.) slag, fly ash, silica fume and limestone dust for applications in Canada.

DESCRIPTION:

To conserve resources and energy, less costly and less energy intensive materials can be used in the production of concrete. The most promising of the less energy intensive materials for replacing cement are granulated slag, fly ash and silica fume. The energy required to produce granulated slag is estimated at only 25% of that for portland cement, and fly ash and silica fume are industrial by-products. As slag and fly ash from different sources have unique properties depending upon the raw materials used, it is essential that investigations be performed to obtain long-term performance data on their use, with and without high-range water reducers, in concrete under Canadian climatic conditions.

INTERACTION:

This project involves in-house research, contract research, cost shared and/or joint projects. Strong links are maintained with the cement, aggregate and concrete industry, and other federal agencies. Some of these are:

1. L.E. Shaw Ltd., Halifax
2. Nova Scotia Hydro, Halifax
3. W.S. Langley and Associates, Halifax
4. Hydro Quebec
5. St. Lawrence Cement Co., Montreal
6. Laboratoire de Béton, Montreal
7. Transport Canada, Montreal
8. Transalta Utilities, Calgary
9. Standard Slag Industries, Fruitland, Ontario
10. Reiss Lime Company Ltd., Blind River
11. Trow Ltd., Toronto
12. Hardy BBT Ltd., Vancouver
13. Kleon Leonoff Consultants Ltd., Calgary

IMPACT:

The use of fly ash in concrete in Nova Scotia was almost nil in 1983-84. The current use of fly ash in concrete in the Halifax area has increased to about 16,000 metric tons annually at a market value of about one million dollars.

CANMET research in fly ashes has led to the development of high volume fly ash concrete which is considered a major break through, and this will increase the use of fly ash in concrete considerably in the years to come.

CANMET research in ferrous and non-ferrous slags has led to the installation of a $4.25 million blast-furnace slag granulation plant at the Algoma Steel mill in Sault Ste. Marie, Ontario, and a $8.7 million grinding plant at Blind River, Ontario, owned by Reiss Lime Company of Canada Ltd., with a production capacity of $150,000 t/y.

The research in silica fume concrete has led to the publication of significant data on the engineering properties of this material, and this, in turn, has led to increased use of this material in Canada and worldwide.

2. ALKALI-AGGREGATE REACTIVITY

OBJECTIVE:

To develop petrographical and mineralogical data on rock types which may be potentially reactive with alkalies from portland cement; to develop engineering data on mineral admixtures to control the above expansive reactions and to evaluate various accelerated tests to predict potential expansion of reactive aggregates in concrete.

DESCRIPTION:

For long-term durability, the aggregates used in concrete must be physically durable and chemically inert. However, in recent years, a large number of cases have been documented where the aggregates have reacted with alkalies from cement and/or de-icing salts and the expansive reactions have resulted in very serious distress to many concrete structures. These include hydro-electric dams, bridges, buildings and concrete railroad ties. The structural damage has been estimated to be in the millions of dollars.

Therefore, it is essential that research be undertaken to identify potentially reactive rock-types, and means be found to control this reaction by the use of supplementary cementing materials. As these reactions are slow and take many years to manifest themselves, it is imperative that accelerated testing methodologies be developed to predict potentially reactive aggregates.

INTERACTION:

This project involves both in-house and contract research with emphasis on the latter. Close contacts are maintained with CSA Standards Committees, provincial and transportation departments, the aggregate industry, concrete consultants and universities in formulating research work elements and transferring technology. Special consideration is given to the problems associated with the Maritime Provinces. The aggregate and cement industry is kept abreast of the new data developed in this research.

IMPACT:

CANMET research in the area of alkali-aggregate reactions has led to the identification of several rock-types in the Maritime Provinces which may be potentially reactive in alkali-aggregate reactions. Engineering data have been developed on the amount and percentage of supplementary cementing materials required to control the alkali-aggregate reactions. This data would assist in formulating clauses for inclusion in national standards. The supplementary cementing materials used include silica fume, blast furnace slag and fly ash. It has also been established that alkali-carbonate reactions can be controlled by replacing a large percentage of cement with granulated-blast furnace slag.

3. CONCRETE FOR OFFSHORE STRUCTURES

OBJECTIVE:

To develop engineering data on high strength, low permeability, and high impact resistant concrete and grouts for offshore structures; to develop concrete permeability and ice abrasion resistance and NDT monitoring of large test specimens installed at outdoor exposure stations.

DESCRIPTION:

Oil exploration and production activities in the offshore and arctic environment are expected to increase in the near future and many of the offshore structures will be constructed of concrete. The performance of concrete structures in the arctic environment is problematic; the extreme cold adversely influences the properties of concrete and ice creates additional problems of abrasion and impact. Studies are performed to develop concretes which will be durable in the arctic environment, with high strength, low permeability and low unit weight. Also, testing methodology is being developed to determine abrasion resistance and permeability of these special concretes.

INTERACTION:

This project involves both in house and contract research but emphasis is on the latter. Strong contacts are maintained with organizations involved in similar activities, especially the oil companies involved in offshore drilling activity, and agencies engaged in long-term research on durability of concrete in the marine environment. Excellent working relations exist between CANMET and U.S. Army Corps of Engineers. For the past eleven years, we have co-operated on the monitoring of the long-term durability of concrete at Treat Island, Maine, an outdoor exposure site operated and maintained by the Corps. CANMET has installed more than 150 concrete prisms at the site.

Regular contacts are maintained with Mobil Oil Research Group in Dallas to plan and discuss research needs in the area of concrete technology for offshore structures.

IMPACT:

CANMET research in high performance concrete for offshore structures has led to the following developments:

1. A large automated testing device to determine the resistance of concrete to ice abrasion and/or impact has been developed. The machine is the only one of its kind in the world and has been utilized by the industry to develop data on the above subject.

2. High-strength lightweight concrete utilizing Canadian expanded shale lightweight aggregate has been developed.

3. Special grouts incorporating silica fume/fly ash/and superplasticizers have been developed and are being used by the industry in the Vancouver area.

4. A uniaxial water-flow permeability test to determine water permeability of concrete has been developed and is being used by the concrete industry.

5. Large concrete panels have been installed at Nanisivik, Baffin Islands, to monitor ice impact and abrasion. This is the only outdoor exposure site in the Arctic.

4. MINE BACKFILL

OBJECTIVE:

To investigate the utilization of metallurgical and industrial wastes for partial or total replacement of portland cement in cemented mine backfill.

DESCRIPTION:

Ferrous and non-ferrous slags possess hydraulic or pozzolanic properties and their use for mine backfill represents a significant operating cost reduction while, at the same time, contributes to the solution of environmental problems such as waste accumulation and soil contamination.

Mining companies have traditionally used portland cement for binding backfill materials, but the need to reduce operating costs has prompted these companies to look into lower cost alternatives. This is particularly true for the Sudbury basin and the Timmins regions of Ontario, where the use of ground granulated blast furnace slag for total replacement of portland cement in mine backfill and of fly ash for partial replacement has become a common practice in recent years. CANMET has been at the forefront of the investigations leading to such innovative practices.

INTERACTION:

Under contract, in 1984, CANMET installed a granulating pilot plant at Algoma Steel #7 blast furnace. The unit power consumption for grinding the product to different finenesses was estimated and the ground slag was characterized by its glass content, chemical composition, hydration reactions, heat evolution rate and total heat evolved, pozzolanic activity and strength development.
A round-robin program was developed to assess the feasibility of using this material for mine backfill. The mines participating in the program were INCO Ltd., Falconbridge Ltd., Kidd Creek Mines and Noranda Inc., Geco Division. The test results showed that in terms of compressive strength, the slag cement performed as well or better than portland cement as the binding agent in cemented mine backfill.

At INCO Ltd., a CANMET-sponsored field test was designed to test the physical properties of the cemented mine backfill prepared using 99.5% slag and 0.5% lime.

IN 1987, CANMET sponsored another round-robin using varying proportions of portland cement, ground granulated blast-furnace slag, lime and backfill materials obtained from each of the mining companies.

INCO Metals Co., Lac Minerals Ltd. (Hemlo Division), Hemlo Gold Mines Inc., Denison Mines Ltd., Teck Corona Operating Corporation and Detour Lake Mines.
CANMET has sponsored two seminars on this topic: "Blast-Furnace Slag Cements for Use in the Mining Industry", was held in Sudbury, Ontario, September 20, 1985 and "Use of Blast-Furnace Slag, Fly Ash and Silica Fume in the Mining Industry", was held in Sudbury, September 21, 1988, with the participation of sixty-five representatives of the mining industry, private, provincial and federal laboratories.

A joint research project is underway with Kidd Creek Mines on the use of ground granulated copper slag in rockfill. Part of the project is a comminution study for reduction of grinding energy cost in which partial results show a reduction of 32%(25 kWh/t) by introducing a roller press-ball mill grinding system.

IMPACT:

INCO Ltd. has totally replaced portland cement by ground granulated blast-furnace slag in mine backfill and has made a five year commitment to buy 120,000 t/y of ground slag each year; Denison Mines has changed its backfill practices and is using 100% blast-furnace slag replacing portland cement; Falconbridge Mines started to use a blend of 50% portland cement/50% ground slag in 1988; Lac Minerals is introducing a modification to its plant to adapt to the use of alternative binders; Placer Dome will start investigating different cementitious materials by the end of 1989 and Hemlo Gold Mines is studying the results of CANMET work.

CERAMICS

GOAL AND SCOPE:

R&D on the production and characterization of various ceramic materials and the transfer of that information to industry. The work covers both functional and structural ceramics and has resulted in the establishment of products and processes in Canadian industry.

Activity is focussed in the following Major Project areas:

1. Development of Piezoelectric Materials
2. Development of Solid Electrolytes
3. Development of Pyroelectric Materials
4. Development of Structural Ceramics
5. Development of Refractory Materials

PERSONNEL:

Two Ph.D's Chemistry
One Ph.D Mineralogy
One Ph.D Electrochemistry
One Ph.D Chemical Engineering
One Ph.D Metallurgy
One Ph.D Solid State Physics
One Ph.D Ceramics
One M.Sc Ceramics
Three Ceramics technologists, one Electronics technologist

Two seconded staff members from industry
One Post Doctoral Fellow (Physics)
Co-op student intermittently

Below are listed the names, qualifications and expertise of all technical and scientific personnel working in this area. An asterisk before the name indicates that a detailed Curriculum Vitae is included in Book Three.

A. Ahmad

B.Sc. University of Karachi, 1968
M.Sc. Chemistry, University of Karachi, 1970.
Ph.D. Photochemistry, University of New Brunswick, 1979. 4 years with CANMET.

Expertise in liquid and solid-state electrochemistry, dielectrics, materials processing and electrical characterization.

J. Aota

B.Eng., Mineralogy & Mining, Kyshu Inst. of Tech., Japan, M.A.Sc., Ceramic Engineering, University British Columbia, 1984. 3 years with CANMET.

Expertise in ceramic engineering, processing, fabrication and evaluation.

J.D. Canaday

B.S. Metallurgical Engineering, University of Oklahoma, 1965. M.Sc. Nuclear Physics, University of Calgary, 1975.
M.Sc. Solid State Physics, University of Guelph, 1978.
Ph.D. Solid State Physics, University of Guelph, 1983. 6 years with CANMET.

Expertise in the electrical characterization of dielectrics.

A.J. Hanson

Dipl. in Ceramic Technology, Canadian Ceramic Society, 1975. 34 years with CANMET.

Expertise in ceramic processing, fabrication and characterization.

***A.K. Kuriakose**

B.Sc. Chemistry, University of Madras, 1953.
M.Sc. Chemistry, University of Madras, 1955.
Ph.D. Chemistry, University of Madras, 1961. 8 years with CANMET.

	Expertise in the synthesis, processing and characterization of ceramics.
A.G. McDonald	Expertise in ceramics processing, fabrication and characterization. 21 years with CANMET.
G. Lemieux	Dipl. in Ceramic Technology, Canadian Ceramic Society, 1976. 24 years with CANMET.
	Expertise in the characterization of ceramics.
V.V. Mirkovich	Dipl. Chemical Engineering, Zagreb, 1950. Ph.D. Chemical Engineering, University of Toronto, 1961. 28 years with CANMET.
	Expertise in heat transfer, thermophysical properties of materials.
G. Pousoukeli	B.Sc. Chemistry, Aristotelian University, 1970. M.Sc. Chemistry, Université de Montréal, 1976. Ph.D. Chemistry, McGill University, 1980. 4 years with CANMET.
	Expertise in solution chemistry, hydrometallurgical processing, ceramic synthesis, statistical design.
D.H.H. Quon	B.Sc. National Sun Yat Sen U, 1950. M.Sc. Mineralogy, Ohio State, 1958. Ph.D. Mineralogy, University of Michigan, 1965. 15 years with CANMET.
	Expertise in mineralogy, crystallography, ceramic processing, fabrication and microstructural characterization.

R. Scharf	Diploma in Electronics Technology, Algonquin College, 1966. 22 years with CANMET. Expertise in custom electronic hardware, circuit design and repair.
S.S.B. Wang	B.Sc. Chemistry, Hong Kong Baptist University, 1966. M.Sc. Chemistry, University of California at Berkeley, 1968. Ph.D. Metallurgy, University of Toronto, 1973. 14 years with CANMET. Expertise in slag chemistry, ceramic processing and characterization.
***T.A. Wheat**	B.Sc Chemistry, Leeds University, 1962. Ph.D Ceramics, Leeds University, 1966. 21 years with CANMET. Expertise in ceramic synthesis, processing, fabrication and characterization.
Guest Researcher: **S. Chehab** **(Post Doctoral Fellow)**	B.Sc. Physics, University of Ottawa. Ph.D. Physics, University of Ottawa.
Industrial Fellows:	
N. Maffei	B.Sc. Physics, University of Toronto, 1981. M.Sc. Physics, Queen's University, 1983. BM Hi-Tech Inc.
M. Saleem	Ph.D. Chemistry. Ceramics Kingston Inc.
Co-op student:	Various undergraduates from programs in Applied Chemistry, Chemical Engineering, Physics.

FACILITIES:

The Section has most of the facilities for a materials development program either within the group or available elsewhere in CANMET.

CAPABILITIES:

The design, synthesis, fabrication and characterization of ceramic materials for industrial applications.

MAJOR PROJECTS:

1. DEVELOPMENT OF PIEZOELECTRIC MATERIALS:

OBJECTIVE:

To develop new piezoelectric materials and processes for industry.

DESCRIPTION:

Have worked closely with industry for many years - the piezoelectric industry in Canada is the result of the work conducted by EMR under DND funding about 25 yrs ago which was then transferred to Almax Industries Ltd. (late 1960's), later to Lakeside Electronics (early 1970's) and more recently to BM Hi-tech Inc. (1984-present).

Projects vary from assistance with production problems to the development of materials for the market place. Typical materials include doped lead and barium titanates, lead zirconate titanate, sodium-potassium niobate and their composites.

INTERACTION:

The collaboration has been extensive and has included the secondment of staff from both Almax and BM to the labs at EMR at various times. Presently concluding negotiations with BM Hi-tech Inc. for a licence to transfer technology for the manufacture of a specific piezoelectric material for which a major market is anticipated in the U.S. in about 5 yrs. BM has seconded a member of staff to the EMR labs to work on joint projects for several years.

IMPACT:

The successful development and transfer of technology in piezoelectric materials has resulted in three companies established in Canada and the permanent employment of 100-130 staff depending on market conditions. Over 70% of production is exported.

2. DEVELOPMENT OF SOLID ELECTROLYTES:

OBJECTIVE:

To develop solid electrolytes for exploitation in energy storage and management systems and environmental sensors.

DESCRIPTION:

Projects vary from the validation or otherwise of literature claims for the behaviour of candidate materials for use in batteries, fuel cells, vapour phase electrolysers and thermoelectric generators to assisting industry with their development programs.

INTERACTION:

As a result of the EMR lead in this field in Canada, programs have been initiated in a number of universities (UBC, McMaster, U of T, Queen's, Concordia, Dalhousie, St Francis Xavier), OrTech and industry (Powerplex Technologies Inc, Almax Industries and Nova Analytical Systems).

In large part, the present submission by the Canadian University-industry Council on Advanced Ceramics (CUICAC) for support under the proposed Network of Centres of Excellence (NCE) which includes EMR and focuses on sensor technology arises from the lead taken by EMR and the deliberate development elsewhere by EMR of capability in the various solid-state dielectric materials.

This capability has also been recognised by the principals involved in a second NCE submission made by the Mining Industry Technology Council (MITEC) which includes work for pyrometallurgical sensors and to which EMR is a proposed contributor.

IMPACT:

Extensive amount of R&D has been conducted in-house: about 12 different systems have been examined in detail. This has included work on oxygen-conductors (the doped zirconias, delta-Bi_2O_3); lithium conductors (the Lisicons $Li_{14}Zn(GeO_4)_4$) and various sodium conductors (beta- and beta"-aluminas, the Na Yasicons and Gasicons, the Nasicons and their ZrO_2-deficient derivatives.

As a result of the in-house program and the identification of undesirable characteristics in some materials, several other programs were terminated: development of lisicons (OrTech), the development of nasicons as sodium conductors (EMR, Almax), the yasicons and gasicons (McMaster).

Sodium-conductors

Current in-house R&D in this field involves support of a $12M program conducted by Powerplex Technologies Inc. (a joint venture between Magna International, Downsview, Brown Boverei & Co., Germany and NASTech, Japan) to develop Na/S batteries for electric vehicles.

R&D into the development of stabilized beta"-alumina was transferred to Almax Industries Ltd. and demonstrated in a thermoelectric generator that was developed and built by the company. It was hoped that Almax would supply Powerplex with the ceramic required for the batteries ... although discussions occurred, no agreement has been reached.

Hydrogen-conductors

The development of this new class of materials was a spin-off of the Na-conductors work above. The process has been patented, the product trademarked and samples are sold from the lab to other labs in the UK, Germany, Belgium, Israel and Japan.

Current in-house R&D focuses on the exploitation of this material in sensor applications in collaboration with Nova Analytical Systems.

A second spin-off from this work arises from the development of a computerized transient analyser under contract to Third Wave Engineering. The company wishes to market the system as a low-cost, general high-speed data logger and analyser based on any MS-DOS system.

As a result of the development and transfer of technology for the production of piezoelectrics and solid electrolytes to industry, CANMET, along with Queen's University and Almax Industries, was the recipient of the Silver Medal in Technology Transfer in the 1986 Canada Awards for Excellence.

3. DEVELOPMENT OF PYROELECTRIC MATERIALS:

OBJECTIVE:

To develop industrially acceptable processes for the production of pyroelectric materials for use in sensors.

DESCRIPTION:

The program is approximately six months old. Initial batches of material have been produced but await characterization by a computerized system that is under development to determine the pyroelectric coefficient. It is planned to also licence this technology to industry when the lab work is completed and industrial pilot-plant work can begin.

INTERACTION:

Discussions have been held with members of the Material Research Lab at Penn State on the evaluation of materials - the materials and the processes remain strictly in-house.

IMPACT:

None - too early to expect significant developments.

4. DEVELOPMENT OF STRUCTURAL CERAMICS:

OBJECTIVE:

The development of high-strength, wear- and impact-resistant materials suitable for use at ambient and elevated temperatures.

DESCRIPTION:

The work has been underway in-house for three years with the purpose of developing and exploiting both oxide and non-oxide systems.

Silicon Carbide: The objective is to understand and optimize the processes that yield sub-micrometre beta silicon carbide in various forms and morphologies, their characterization and final fabrication into sintered monoliths. So far, progress includes the development of sub-micrometre single-phase ß silicon carbide powder on a lab scale and the identification of the mechanisms and processes that operate in the control and growth of material with a specific morphology (equiaxed powders, plates or fibres).

Composites: Wear resistant ceramics have been projected by many to have a growing market. Applications include service at both ambient and elevated temperatures. The former can well exploit the zirconia-toughened systems whereas the latter usually depend on the non-oxides and their composites.

Oxide Based
The essence of this work is the development of materials having nearly three-times the wear resistance and four-times the impact resistance for a cost increase of approximately 30% over the base material. The program has focussed on both ZrO_2-toughened alumina and mullite.

Non-oxide Based
This has been a largely external program conducted in collaboration with Electrofuel Manufacturing Co. The purpose is the development of wear and impact-resistant materials for use in raw materials handling equipment.

INTERACTION:

Silicon Carbide: The development of SiC of controlled morphology was conducted in close collaboration with Ceramics Kingston who seconded a member of staff to EMR for two years while this program was underway - the company is in the process of piloting the process.

Zirconia-toughened Alumina: The technology for the production of this material has been transferred to Electrofuel Manufacturing who are piloting the process.

Non-oxide Composites: Still under joint development with Electrofuel Manufacturing Co. The program had the objective of developing high-temperature wear resistant materials. The durability of the material produced has been validated by two Divisions of the NRC who independently evaluated the materials produced:

- as the valve in a single-cylinder diesel engine operated for 500 hrs - no sign of wear or distress was found (conducted by the Fuels and Lubricants Division, NRC).
- as a cutting tool for which major markets are developing. NRC showed they were superior to any of the inter-national competition Manufacturing Technology Centre. The company is actively promoting the product to North American, European and Japanese users.

IMPACT:

Two companies piloting three products developed in collaboration with EMR. Production will be largely for export.

5. DEVELOPMENT OF REFRACTORY MATERIALS:

OBJECTIVE:

To provide assistance to both producers and users of refractory products.

DESCRIPTION:

Although work in the section used to focus on the development of refractories from Canadian resources, in the last five years all work has been in response to industrial requests for assistance. This is a result of the change in the industry from the use of naturally occurring materials to the increasing use of synthetic composites, which the lab is ill-equipped to process, e.g., resin- and pitch-bonded MgO and dolomite brick.

INTERACTION:

Recent work has included a detailed analysis of MgO-C refractory (Atlas Steels), and evaluation of the failure mechanisms of refractories use in steelmaking vessels. Viscosity measurements of slags for optimization of mineral wool production were provided to Pacific Enercon. Technical assistance was provided to Canadian Steel Foundries in solving their problems associated with refractory nozzle and nozzle stopper blockage during casting. Examination of alumina-mullite refractory degradation in rotary calciners operated by (Timminco) has proven critical to alloy production.

IMPACT:

As a result of this continuing maintenance of expertise in the field, the group has been invited to contribute to a third NCE proposal made by CISRA for a program on Advanced Steels.

ANALYTICAL STANDARDS AND METHODS

GOAL AND SCOPE:

To ensure the reliability and quality of chemical and physical measurments primarily in support of mineral R&D projects and to contribute to the development of national and international standards.

Activity is focussed in the following Major Project areas:

1. Reference Materials Project

2. Analytical Methodology

PERSONNEL:

Four Ph.D. Chemists
One Ph.D. Physicist
One M.Sc. Chemist
Four B.Sc. Chemists
One B.A. Chemist
Four technologists/technicians

Below are listed the names, qualifications and expertise of all technical and scientific personnel working in this program area. An asterisk before the name indicates that a detailed Curriculum Vitae is included in Book Three.

Dwight J. Barkley — B.Sc. in Chemistry from Carleton University, 1955.

Analytical chemistry in method development in various analytical techniques including solvent extraction, ion-exchange, ultra-violet and light absorption, and fluorescence spectrometry, potentiometric titrimetry using non-aqueous solvent and specific ion electrode techniques and atomic-absorption flame spectrometry; special focus in recent years has been on high-performance liquid chromatography, gas chromatography and flow injection analysis, with research and development of methods and separation systems for the

determination of ionic and organic species.

As a member of ISO Technical Committees 17 (Steel) and 26 (Copper), and as Canadian Coordinator for testing program ISO/TC 17/WG 12, many proposed international standard methods have been reviewed. Thirty six years at CANMET.

W.S. Bowman

B.Sc. (Carleton) 1965.

Applications of statistical methodology in the mineral industry. Statistical evaluation of extensive interlaboratory experimental programs for the certification of reference materials and for the development of standard methods of chemical analysis; determination of consensus values, measure of precision and other parameters.

Design, development and maintenance of systems of programs and databases in both micro and mainframe computer environments. Twenty three years at CANMET.

J. Lloyd Dalton

B.Sc. (Hons.) U. of Manitoba 1962.
M. Eng. Carleton U. 1970.
C. Chem.

Specialization in X-ray fluorescence spectrometry, radiochemistry, the analytical chemistry of uranium, and some exposure to process control. Twenty five years at CANMET.

***Elsie M. Donaldson**

B.Sc. (Honours Chemistry) 1951, University of Manitoba.

In analytical method development, solvent extraction and separation techniques based on co-precipitation, volatilization and electrodeposition, as applied to the determination of small and trace amounts of diverse elements in mineralogical and metallurgical materials by

instrumental techniques such as flame photometry, light-absorption spectrophotometry, flame, graphite-furnace and hydride-generation atomic-absorption spectrometry. This also includes expertise in classical "wet-chemical" analysis of ores, rocks and related materials. Thirty five years at CANMET.

John A. Graham

Diploma in Chemistry from Ryerson Polytechnical Institute, 1967. B.Sc.in Chemistry from Carleton University, 1980.

Experience in mineral analysis incorporating fire-assay, HPLC, flame-AAS, ICP-AES. hydride-generation, electro-chemical, spectrophotometric and FIA techniques with some emphasis in high accuracy and precision analytical method development for international standards. Twenty two years at CANMET.

René J. Guillas

Diploma in Chemical Technology (1972) Red River Community College, Winnipeg, Manitoba.
Chartered Chemist registered with The Association of the Chemical Profession of Ontario

Analysis of a wide variety of complex materials (ores, minerals, rocks and products from ore processing and metallurgical operations), utilizing a variety of techniques, including classical gravimetric procedures and instrumental techniques such as atomic absorption spectro-photometry. Experience in the evaluation, modification, and testing of proposed methods for use as international standard methods for ISO and ASTM. Provision of highly accurate and precise analytical data in the certification of standard reference materials. Eight years at CANMET.

Jack C. Hole

B.A. (Chemistry), University of Toronto.

Experience in mineral analysis incorporating fire-assay, flame-AAS, ICP-AES, spectrophotometric and volumetric techniques. Some emphasis in high accuracy and precision analytical method development for international standards, and the involvement in analytical standards committees at the international level. Twenty eight years at CANMET.

Robert H. McCorkell

B.Sc.(Hons.)1961
Ph.D. 1964, U. of Manitoba.

Analytical chemistry, radiochemistry and the application of etched-particle-track methods in geology and chemistry. In analytical chemistry chief expertise is in "classical" or "wet" methods as adjunct to instrumental analyses performed by others. Eight years at CANMET.

Donald G. McIntosh

4 years Secondary School

Milling, screening and bottling for the Canadian Certified Reference Materials Project. Milling and leaching of uranium ores. Sixteen years at CANMET.

Patrick E. Moloughney

Northern College of Applied Arts and Technology, Haileybury School of Mines Campus.

Analytical chemistry of the precious metals, particularly those of the platinum group. Development of analytical methods and the modification of existing methods for the determination of platinum, palladium, rhodium, iridium, ruthenium, gold and silver in a wide variety of materials. Accurate and precise analysis of reference materials. Thirty-three years with CANMET.

***Clinton W. Smith**

B.Sc.(1966), U.of Alberta (Calgary)
M.Sc. (1969), U. of Calgary
Ph.D. (1974), Queen's University.

Sixteen years post-graduate experience in instrumental analytical chemistry and radio- chemistry applied to mineralogical/metallurgical materials. Measurement project coordination and evaluation. Expertise in electro chemistry, X-ray fluorescence spectrometry, gamma-ray spectrometry, analytical geochemistry and applied statistics. Sixteen years at CANMET.

***Henry F. Steger**

B.Sc. 1965, McMaster University
Ph.D. 1969, McMaster University

Research chemistry in inorganic metal complex chemistry, base metals adsorption by clays and ambient oxidation of sulphide minerals. Expertise in the development of analytical methods. Experience in experimental design in the study of the geochemistry of and the coordination of the development of a model for the simulation of acid generation in mine process tailings. Expertise in the certification of reference materials and development of practical concepts and statistical design for the use of these materials in the analytical laboratory. Currently, Manager of the Chemical Laboratory of the Mineral Sciences Laboratories of CANMET. Twenty years at CANMET.

***Robert Sutarno**

B.E. (1960) in Chemical Engineering
M.E. (1963) in Chemical Engineering
Ph.D. (1965) in Solid State Chemistry,
Technical University of Nova Scotia

Various applications of statistical techniques in mining and mineral processing industries: bulk sampling, accuracy of measurement methods, process quality control, nuclear

materials inventory, preparation and uses of reference materials, laboratory certification, specifications, laboratory quality control, sampling mine dust, etc. Twenty four years at CANMET.

***Michael G. Townsend**

Ph.D. 1959, University of Southampton, UK
F. Inst. P. 1972, Institute of Physics, London, UK.

Solid-state physics and chemistry, chemical physics and in radiation including electrical, magnetic, optical, infra-red, fluorescent, magnetic resonance and Mossbauer properties of metals, insulators, semi-conductors, glasses, polymers, minerals, molecules; neutron scattering in minerals; cracking of bithumen tar sands; device physics; acoustic-spin wave interaction in solids; Radiation and Health and Safety of Miners. Magnetic separation for minerals beneficiation. Twenty one years at CANMET.

Peter Westra

Secondary school diploma, Several chemistry courses (Eldorado Nuclear).

Preparation of a wide variety of compositional reference materials by the Canadian Certified Reference Materials Project for use in the mining and metallurgical industries and research institutions.

Maintenance of appropriate computer files, processing purchase orders, communications with national and international clients, planning and purchasing equipment. Fifteen years with CANMET.

FACILITIES:

MSL is well equipped with modern analytical and physical characterization instrumentation. An inductively coupled plasma-mass spectrometer is being acquired.

CAPABILITIES:

- preparation/certification of reference materials
- statistical design and development for use of reference materials
- development of high accuracy and precision analytical methods
- organization and coordination of interlaboratory analytical programs for reference materials and methods
- variable magnetic field/temperature Mossbauer and magnetic susceptibility measurements

MAJOR PROJECTS:

1. REFERENCE MATERIALS PROJECT:

OBJECTIVE:

The Canadian Certified Reference Materials Project (CCRMP) identifies, prepares, certifies and makes available reference materials of composition which are applied to ensure the reliability and quality of chemical measurements carried out by laboratories serving Canadian minerals and metallurgical industries, publishes results of its interlaboratory measurement studies, and conducts research on production, statistical methodology of certification, and application of reference materials.

DESCRIPTION:

Certified reference materials (CRMs) are applied by analytical laboratories to ensure the accuracy (trueness) of their measurements, and to test quality of potentially more efficient methods undergoing development.

The materials prepared as candidate CRMs are the raw materials, products, and by-products of industry, having relevance to measurements for geochemical exploration, mill process control, product valuation and commodity specifications, and waste-product control. The present inventory of available samples comprises 78 materials classified as rocks, soils, ores, mineral concentrates, mill tailings, metals and alloys.

CCRMP prepares and characterizes the candidate materials, organizes measurement programs for certification, performs analysis of the results, publishes certification

documentation, and makes test samples available to the scientific public.

Scientists involved in CCRMP also undertake research to develop statistical concepts and design for certification procedures and the proper application of reference materials, and to establish properties of homogeneity, stability and analytical accuracy commensurate with certification.

Increasingly, CCRMP is also used as a resource information centre for availability of reference materials for specific needs from the world-wide network of CRM producers.

INTERACTION:

CCRMP focuses on the needs of the Canadian mineralogical and metallurgical industries. These needs are identified through CANMET/ industry interactions, principally through the CCRMP Advisory Committee, which consists of members from the Canadian industrial, commercial laboratory and institutional laboratory sectors. The Advisory Committee meets annually to review progress and recommends priorities of objectives.

Each reference material typically involves the contribution of measurements by fifteen to thirty laboratories from the industrial, commercial, and institutional sectors from Canadian and frequently international sources. User-laboratories also provide feedback on the needs for future CRMs and an increasing pool of participants on which CCRMP may draw.

At the request of the Standards Council of Canada, scientists from CCRMP represent Canada at the Council Committee on Reference Materials (REMCO) of the International Organization for Standardization (ISO). This body undertakes development of Standards for the preparation, certification and use of CRMs.

IMPACT:

CRMs contribute through improved reliability of measurements made in laboratories serving Canada's minerals and metallurgical industries. Accuracy of such measurements has bearing on important questions, e.g.: - is this area worthy of further exploration? - is this ore body economic? - is our copper concentrate undervalued? - are we meeting emission control specs?

Sales of CCRMP materials - 1,921 units in FY 1988, an increase of 33% over 1985 -provide evidence that CRMs are valued and increasingly applied by laboratories. Canadian

laboratories frequently cite the use of CCRMP CRMs in explanations of their quality assurance programs.

CCRMP materials have international recognition. They have been catalogued in compendia of reference materials, e.g. as produced by ISO and the journal Geostandards Newsletter. Its materials are distributed by importing agencies in several countries: approximately 1,700 laboratories in 68 countries have purchased CCRMP materials.

International recognition in part accrues from pioneering CCRMP endeavors to produce CRMs of sulphide ores and concentrates, gold ores, and uraniferous radiometric materials of identified Canadian need and not available elsewhere in the world. High-aluminum zinc alloys and geochemical materials for platinum group alloys, the former just introduced, and the latter under development are also of international interest.

CCRMP certification measurement programs provide a scientific study of the status quo of consensus of measurement methods and thereby a yardstick for improvements. The published literature of new mineralogical analytical methods frequently cite results of tests on CRMs. CRM are therefore an important link in the chain of technology transfer leading to improved efficiency and accuracy.

Research on statistical designs for the use of CRMs to validate the accuracy of analytical methods and the significance of CRM stability to users have been published by CCRMP scientists. The former have been adopted by ISO for publication in Guide 33: "Uses of certified reference materials" and Standard 5725 Part 4 "Accuracy of measurement methods - Basic methods for estimating the trueness of a test method."

Participation in REMCO ensures Canada's perspective on, and input to the development of international standards for reference materials.

CCRMP has been recognized by other government bodies (e.g. Environment Canada, International Atomic Energy Agency) and and industry (e.g. Alcan International Limited, Newmont Exploration Ltd.) as a resource centre for preparation of reference materials for their specific requirements.

2. ANALYTICAL METHODOLOGY:

OBJECTIVE:

To develop and improve analytical methods, techniques and laboratory facilities, and to participate in national and international working groups that develop and disseminate information on standard analytical methods.

DESCRIPTION:

The Analytical Methodology Project strives to coordinate the development and improvement of analytical methods and techniques undertaken by CANMET's Mineral Sciences Laboratories in support of, and in response to, the wide variety of materials arising from in-house research and development projects. Analytical method development is also conducted in response to specific problems encountered by Canadian industry. This work is carried out on a co-operative basis with clients to assist them with the control and improvement of their processes or products. Some major areas of research and technological development within the last 5 years include:

-development of instrumental methods based on flame, graphite-furnace and hydride-generation atomic-absorption spectrometry, X-ray fluorescence, inductively-coupled plasma-optical emission spectrometry, gas and ion-exchange liquid chromatography, alpha and beta spectrometry, gamma-ray spectroscopy, fission-track dating and Mssbauer spectroscopy. Future instrumental techniques will include inductively-coupled plasma-mass spectrometry and Zeeman graphite-furnace atomic-absorption spectrometry.

-development of a prototype flow injection analyzer for the determination of cyanide in gold mill effluents

-publication of a working manual of assay methods used in CANMET for the determination of the precious metals.

CANMET participation in national and international working groups, such as the International Standards Organization (ISO) and the American Society for Testing and Materials (ASTM), is in collaboration with the Canadian mineral and metallurgical industries. Seven of these firms work with CANMET to establish standard methods for the analysis of base metal ores and concentrates in which Canada has an annual production and trade worth several billion dollars. Four companies are also involved in standard method development for each of steel, copper and copper alloys and iron ore. CANMET has also assisted in the production of a methods

manual for the uranium industry for the International Atomic Energy Agency (IAEA).

INTERACTION:

Although the Analytical Methodology Project is concerned mainly with research and analytical method development to support CANMET's in-house research and revenue-generating projects, research is also carried out for, and in collaboration with, many major Canadian industries, other federal organizations, provincial research councils and universities. Highly-specialized analytical consultation is also provided on a national and international basis to resolve specific technical problems.

Within the last 5 years Chemical Laboratory personnel visited numerous analytical laboratories and attended national and international conferences focussed on analytical chemistry. Courses were given on X-ray fluorescence analysis and fission-track dating technology.
Personnel serve on many national and international technical committees such as the International Standards Organization, International Atomic Energy Agency, Natural Sciences and Engineering Research Council, Canadian Standards Association, Canadian Uranium Producers' Metallurgical Committee, Chemical Institute of Canada and the American Society for Testing and Materials (ASTM).

IMPACT:

The continual development of new analytical methods and techniques and the refinement and modification of existing methodology are essential to keep pace with recent improvements in analytical technology and to enable the CANMET Chemical Laboratory to extend its analytical capability to respond to the ever-increasing demands for faster and more accurate analytical results for a wide variety of complex materials arising from in-house and revenue-generating research projects. Accurate analytical data are extremely important to CANMET's Certified Reference Materials Project which prepares and certifies reference materials for world-wide sale. Special expertise has been built up in the analysis of trace elements and in the use of modern instrumental techniques. Chemical journals often request Laboratory staff to review technical papers.

Since 1984, 36 technical papers and one book have been published in the open literature, 3 seminars have been presented to Canadian organizations and 24 papers have been presented at various national and international chemical conferences. Numerous requests for reprints of papers and

use of CANMET methods by the Canadian mining community and other international laboratories indicates the acceptance of CANMET's research work by outside organizations.
A manual entitled "Assay Methods for the Determination of Precious Metals" is currently a best-selling CANMET publication. An earlier, more comprehensive laboratory manual entitled "Methods for the Analysis of Ores, Rocks and Related Materials", is still in demand at both the national and international level.

CANMET's participation in international organizations such as ISO and ASTM, which are responsible for the establishment of international standards for a wide range of materials and products, aids in the development of analytical methods to ensure that these standards are both equitable and applicable to Canadian conditions. These facilitate orderly trade in commodities, and Canada as a large exporter could be significantly affected with regard to both the value and the acceptability of Canadian mineral and metallurgical products in international markets.

Since 1985, five visiting Fellows from the International Atomic Energy Agency, CETEM, Brazil, and LNETI, Portugal, were accommodated for periods varying from four weeks to four months for updating their skills in analytical methodology for uranium and base metal mineral products.

ANALYTICAL SERVICES:

Analytical method development and analytical support services are closely interrelated, particularly for in-house research studies, and it is often very difficult to assign unequivocally the effort of the personnel of the Chemical Laboratory to one area or other. For this reason, the names, qualifications and expertise of previously unreferred-to professionals and technologists and technicians are listed below.

James E. Atkinson	B.Sc. Queen's University, 1952 Application of wet chemical and instrumental techniques to the analysis of steels, alloys, and metallurgical processing samples. Thirty-six years at CANMET.
Marcia C. Blanchette	B.Sc. (1984), M.Sc. (1987) Chemistry University of Ottawa Research in low molecular weight cations by mass spectrometry. Developing experience in

radiochemistry and X-ray fluorescence. Six months at CANMET.

Donald W. Carson

Electronic Technologist Diploma
Algonquin College

Development, modification and evaluation of electronic instruments. Modification and testing of computer programs for the technical analysis of data and the display of results and for the control of experiments. Experimental measurement of the electrical, magnetic and Mossbauer properties of minerals. Twenty-three years at CANMET.

Richard Charbonneau

Secondary school diploma

Development and modification of liquid chromatographic procedures for determination of metals, anionic and organic species in metallurgical processing products. Expertise in atomic-absorption spectrometry, alpha and beta spectrometry, fluorimetric analysis, X-ray fluorescence, and classical wet chemistry methods. Fifteen years at CANMET.

Marc Chénier

D.E.C. en Chimie analytique 1985,
CEGEP de l'Outaouais

Application of analytical methods for anions and organic compounds by high performance liquid, capillary and gas chromatography, flow injection analyzers and inductively coupled plasma emission spectrometers. Three years at CANMET.

T. Roy Churchill

B.Sc. (Honours Chemistry), University of Western Ontario 1952.
Optical emission techniques such as arc, spark and inductively coupled plasma spectrometry applied to the quantitative determination of major, minor and trace elements in rocks, minerals and metallurgical materials.

	Radiochemistry of the production, separation and measurement of radioisotopes.
	Development and maintenance of microcomputer programs applied to spectrometric techniques and a network laboratory sample tracking and reporting system. Seventeen years at CANMET.
Jean Cloutier	Chemical Technologist (CEGEP de Hull)
	Certificate in Administration (Québec University)
	Development, modification and application of methods for the analysis of ores, rocks and related materials. Expertise in classical wet chemistry and in fire-assay for the analysis of the precious metals. Nineteen years at CANMET.
Eliza Cyfracki	Diploma in Chemical Technology, Gdansk, Poland. Three years of study in medical technology at Windsor Community College.
	Application of a wide variety of inorganic analytical chemical operations and the operation of diverse types of spectrometers, industrial shipyard and water treatment plant experience. Uranium umpire analysis. Eight years at CANMET.
Leo E. Desjardins	Secondary school diploma
	Chemical analysis of ores and mineral processing products using classical analytical techniques, and instrumental techniques including atomic-absorption spectrophotometry, colourimetry and autotitrimetry. Thirty-four years at CANMET.
Roger A. Fortin	Diploma in Analytical Chemistry, CEGEP Hull, Chemistry courses at Algonquin College and Carleton University.

Application of a wide variety of inorganic analytical chemical operations and the operation of diverse types of spectrometers and also experience in food chemistry. Twenty-six years at CANMET.

R.E. Horton

B.Sc. 1964, Carleton University.

Application of optical emission spectrochemistry using a variety of excitation sources including ICP and also expertise in general analytical chemistry. Twelve years at CANMET.

R. Karwowska

M.Sc. 1967, Ph.D. 1976, Analytical Chemistry, University of Warsaw, Poland.

Research in trace metals analysis. Application of trace metals analysis, general analytical chemistry, elecroanalytical chemistry, and spectrochemical measurements. Three years at CANMET.

Maureen E. Leaver

B.Sc. (Honours Chemistry) 1977, Queen's University.

Analytical method development based on solvent extraction, separation techniques, electrochemistry, radiochemistry and several spectrometries for trace elements in mineral products. Uranium umpire analysis. Ten years at CANMET.

Earle H. MacEachern

B.Sc. Mount Allison University 1954

Application of the analysis of metals, steels, and alloys by instrumental and wet chemical methodology. Thirty-four years at CANMET.

L. E. McCulloch

Diploma in Chemical Technology, Algonquin College, 1971.

Modification of analytical methods, and chemical analysis of mineral processing products by classical and

instrumental techniques. Experience in precious metals analysis. Experience in statistical evaluation of analytical data for accuracy and precision. Twenty-three years at CANMET.

Grant L. Nelson

Secondary school

Application of wet chemical and instrumental techniques to the analysis of steels, alloys, and metallurgical processing samples. Thirty-two years at CANMET.

Gerald W. Richardson

B.A. (Gallaudet University, Washington, D.C.) 1971

Chemical analysis of ores and mineral processing products using classical analytical techniques, and instrumental techniques including atomic-absorption spectrophotometry, colourimetry and autotitrimetry. Eighteen years at CANMET.

Marko N.Sawchyn

Diploma, Chemical Technology, Dawson CEGEP, Montreal, Several courses leading to a B.Sc. in Chemistry and a B.A. in Economics.

Analytical methods for analysis of a wide range of elements in ores and mineral processing products. X-ray and optical fluorescence, alpha and beta spectrometry and fluorimetry in radiochemical analyses. Corrosion experience in hydrogen stress cracking, environmental stress cracking and polarization behaviour. Electroplating and deposition of printed circuit boards. Eleven years at CANMET.

D.S. Sheldrick

High School graduate. Four courses in chemical technology at Algonquin College.

Application of a wide variety of inorganic analytical chemical operations and the operation of

diverse types of spectrometers. Thirty-four years at CANMET.

Robert J. Tremblay

Diplome en Electronique, Institut de Technologie de Hull.

Development, construction and maintenance of instruments. Experimental measurements in Mossbauer spectroscopy, magnetic susceptibility, radiation dosimetry, etc.

Computer technology applied to instrument control and data acquisition and analysis, including both hardware and software.

Joachim W. Wittwer

B.Sc. (Honours Chemistry) 1976, Carleton University.

Chemical analysis of ores and mineral processing products using classical analytical techniques, and instrumental techniques including atomic-absorption spectrophotometry, colourimetry and gas chromatography for organic and inorganic constituents in ores, metals and environmental products.

Interpretation and implementation of initiatives in Occupational Health and Safety, WHMIS, and waste management in the laboratory environment, including preparation of seminars, training packages, and data bases. Eight years at CANMET.